



Contribution à l'étude des mouvements forts en Iran : du catalogue aux lois d'atténuation

Mehdi Zare

► To cite this version:

Mehdi Zare. Contribution à l'étude des mouvements forts en Iran : du catalogue aux lois d'atténuation. Géophysique [physics.geo-ph]. Université Joseph-Fourier - Grenoble I, 1999. Français. NNT : . tel-00708207

HAL Id: tel-00708207

<https://theses.hal.science/tel-00708207>

Submitted on 14 Jun 2012

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



OBSERVATOIRE DE GRENOBLE

et

LABORATOIRE DE GÉOPHYSIQUE INTERNE ET TECTONOPHYSIQUE

THÈSE

présentée par

Mehdi ZARÉ

pour obtenir le titre de DOCTEUR de

L'UNIVERSITÉ JOSEPH FOURIER - GRENOBLE I

(Arrêtés ministériels du 5 juillet 1984 et du 30 mars 1992)

Specialité: Géophysique - Géochimie - Géomécanique

**Contribution à l'étude des mouvements forts en Iran; du catalogue
aux lois d'atténuation**

20 AOÛT 2003

Date de soutenance: 9 Mars 1999

Composition du jury:

Composition du jury:

P.-Y. Bard	Directeur de Thèse	Ingénieur au LCPC, Paris
M. M. Campillo	Président	Professeur à l'Université Joseph Fourier, Grenoble
Y. Fukushima	Rapporteur	Shimizu Corporation, Tokyo, Japon
M. Ghafory-Ashtiany	Invité	Président de IIEES, Téhéran, Iran
D. Hatzfeld	Examineur	Directeur de Recherche CNRS au LGIT, Grenoble
B. Mohammadioun	Rapporteur	Conseiller auprès de l'IPSN, Paris
P. Mouroux	Examineur	Directeur de Recherche au BRGM, Marseille

Univ. J. Fourier - O.S.U.G.
MAISON DES GEOSCIENCES
DOCUMENTATION
B.P. 53
F. 38041 GRENOBLE CEDEX
Tél. 04 76 63 58 27 - Fax 04 76 51 40 58
Mail: ptaloue@ujf-grenoble.fr

OBSERVATOIRE DE GRENOBLE
et
LABORATOIRE DE GÉOPHYSIQUE INTERNE ET TECTONOPHYSIQUE

THÈSE

présentée par

Mehdi ZARÉ

pour obtenir le titre de DOCTEUR de

L'UNIVERSITÉ JOSEPH FOURIER - GRENOBLE I

(Arrêtés ministériels du 5 juillet 1984 et du 30 mars 1992)

Specialité: Géophysique - Géochimie - Géomécanique

**Contribution à l'étude des mouvements forts en Iran; du catalogue
aux lois d'atténuation**

Date de soutenance: 9 Mars 1999

Composition du jury:

P.-Y. Bard	Directeur de Thèse	Ingénieur au LCPC, Paris
M. M. Campillo	Président	Professeur à l'Université Joseph Fourier, Grenoble
Y. Fukushima	Rapporteur	Shimizu Corporation, Tokyo, Japon
M. Ghafory-Ashtiany	Invité	Président de IIEES, Téhéran, Iran
D. Hatzfeld	Examineur	Directeur de Recherche CNRS au LGIT, Grenoble
B. Mohammadioun	Rapporteur	Conseiller auprès de l'IPSN, Paris
P. Mouroux	Examineur	Directeur de Recherche au BRGM, Marseille

10204083

Quand la terre tremblera d'un violent tremblement,
et que la terre fera sortir ses fardeaux,
et que l'homme dira: Qu'a-t-elle?!

Le Saint Coran; Zelzaal (1 à 3)

A mon père; Mohammad

A ma mère; Fatemeh

A mon frère; Mehrdad

A l'esprit de mon oncle qui

est mort pour sa patrie; Radjab Nasiri (1965-1986)

et à l'esprit de son ami; Amir-Reza Keshmiri (1964-1987)

A la prospérité de l'Iran dans

21ème siècle... inshaallah!

CONTRIBUTION À L'ÉTUDE DE MOUVEMENTS FORTS EN IRAN; DU CATALOGUE AUX LOIS D'ATTÉNUATION

Les études de risque sismique en Iran sont dans leur phase initiale. Ainsi, il n'existait jusqu'à présent aucun catalogue d'enregistrements accélérométriques en Iran, et aucune étude sur l'ensemble des données iraniennes n'avait été réalisée. Ce mémoire présente donc la première étude d'ensemble sur les mouvements forts en Iran. Un premier objectif a été d'établir un catalogue des mouvements forts d'Iran en faisant correspondre à chaque enregistrement de qualité suffisante, un événement sismique de localisation et magnitude connues, pour 279 enregistrements accélérométriques, analogues et digitaux. Cette correspondance a pu se faire sur la base des catalogues sismologiques internationaux (ISC, NEIC,... etc.) ou nationaux. Pour 189 autres enregistrements numériques, pour lesquelles aucune information télésismique ou locale n'était disponible, les distance hypocentrales et les moments sismiques ont été estimés sur la base des enregistrements eux-mêmes. Une attention particulière a été accordée aux effets de sites, en choisissant notamment 50 stations accélérométriques du réseau national où les enregistrements ont été nombreux. Une nouvelle classification pour les effets de sites est proposée -basée sur les rapports H/V - qui s'avère relativement simple dans son principe, et plus fiable que les classifications déjà utilisées. Finalement, les lois d'atténuation pour différents paramètres de mouvement fort (dont Arms, Intensité Arias, PGA, PGV, et PGD, énergie, durée et valeurs spectrales) sont obtenues et discutées sur la base d'un total de 468 enregistrements accélérométriques en 3 composantes.

CONTRIBUTION TO THE STRONG MOTION STUDIES IN IRAN; FROM THE CATALOG TO THE ATTENUATION LAWS

The seismic risk studies in Iran are in the first stages. Till now, no catalog of strong motion accelerograms was existing in Iran, and no study has been conducted on the entire of the strong motion data. This thesis presents therefore the first study on the whole strong motion data-set in Iran. A first objective in this work was to establish a catalog of strong motion to assign to each record - of a satisfactory quality - a seismic event with known location and magnitude. Such correspondance was possible based on the international (NEIC, ISC, ...etc) or national seismologic catalogs, for 279 analog and digital accelerograms. For 189 other digital data, for which no teleseismic or local information was available, the hypocentral distance and the moment magnitude are estimated based on each record. A special attention was paid to site effects, choosing 50 strong motion stations of the national network, where there were a lot of records. A new classification for site effects is proposed - based on the H/V ratio - which is relatively simple, and more reliable than the previously proposed methods. Finally, the attenuation laws for different parameters of strong motion (such as Arms, Arias intensity, PGA, PGV, and PGD, energy, duration and the spectral ordinates) are obtained and discussed, based on the whole set of 468 three-component accelerometric records.

پژوهش و بررسی جنبش شدید زمین در ایران : از کاتالوگ تا قانونهای کاهندگی

پژوهشهای خطر زمینلرزه در ایران هنوز در گامهای نخستین می باشد. پیش از مطالعات ارائه شده در این رساله هیچ کاتالوگی از جنبش شدید زمین در ایران وجود نداشته است. از سوی دیگر تاکنون مطالعه ای جامع بر روی داده های شتابنگاری ایران صورت نگرفته است. بنابراین رساله حاضر اولین مطالعه بر روی تمام داده های شتابنگاری ایران می باشد. یک هدف اولیه این مطالعات تهیه کاتالوگ جنبش زمین ایران بود که در آن برای ۲۷۹ نگاشت ۳ مولفه ای آنالوگ و دیجیتال - که کیفیتی مناسب داشتند - اطلاعات جنبش زمین و سرچشمه ارائه شد. داده های سرچشمه بر اساس گزارش مرکز های جهانی و کشوری گردآوری شد. برای ۱۸۹ نگاشت دیجیتال که که گزارشی از سرچشمه آنها در دسترس نبود فاصله کانونی و بزرگای گشتاوری آنها بر اساس خود نگاشتها محاسبه گردید. اثرهای ساختگاه با انتخاب ۵۰ ایستگاه شتابنگاری - جایی که بیشترین نگاشتها بدست آمده بود - مطالعه گردید. یک روش جدید برای طبقه بندی ساختگاه پیشنهاد شد که اساسی ساده و کارایی بیشتری از روشهای پیشین دارد. در نهایت قانون های کاهندگی برای پارامترهای مختلف جنبش زمین (بیشینه شتاب، سرعت و تغییر مکان، انرژی، دوام و مقدار های طیفی) بر اساس پایگاه داده هایی با ۴۶۸ نگاشت شتابنگاری بدست آمده و مورد بحث قرار گرفت.

Remerciements

Comment peut-on être persan!?

Montesquieu

La question posée par Montesquieu est celle que je me pose toujours!, surtout depuis le temps que je voulais faire mon doctorat en France... pour celui qui vient d'un pays avec un risque très important de séismes majeurs, la réponse pourrait être "Étudier le mouvement fort en Iran!". Un sujet qui n'avait jamais été étudié avant, et en même temps, un travail assez important...

Il y a 5 ans, dans mon mémoire de M.Sc., j'ai écrit "il faut continuer les études sur les mouvements forts en Iran, sur la base de l'ensemble des données de l'Iran, inshaallah...". Aujourd'hui, quand je vois que mon rêve de ce jour-là est devenu une réalité, il faut d'abord que je remercie le bon Dieu, qui m'ai fourni la possibilité de faire ce devoir.

Dans ce travail, qui m'a imposé au départ et à la fin des difficultés majeures, après le bon Dieu qui m'a donné cet esprit amoureux pour travailler pour mon pays(!), il faut que je remercie mon directeur de thèse; M. Pierre-Yves Bard. Pierre-Yves était présent dans ce travail de la première jusqu'à la dernière minute pour m'assister (moralement, scientifiquement,etc.) et me montrer le chemin. Je remercie P.-Y. Bard, pas seulement pour diriger ce travail, mais aussi pour m'avoir montré "comment peut-on être humain?"!.

Le président de l'IIIES (International Institute of Earthquake Engineering and Seismology) à Téhéran (où je travaille), M. Ghafory-Ashtiany m'a fourni tout ce dont j'ai eu besoin. Il a fait vraiment de son mieux et ses efforts ont été vraiment impressionnants: s'il n'y avait pas eu son assistance en Iran, je peux imaginer que le travail que j'ai fait pendant ces trois ans et demi aurait été impossible.

Je remercie les membres de jury, M. Mohammadioun et M. Fukushima, qui ont accepté d'être rapporteurs de ma thèse, M. Campillo, M. Mouroux et M. Hatzefeld qui ont y assisté comme les examinateurs.

Un grand merci à ma famille: mon père; Mohammad, ma mère; Fatemeh, et mon frère,

Mehrdad qui ont été toujours avec moi pendant ce travail, malgré leur absence physique de France. Etre loin d'eux, était mon problème le plus important quand j'étais en France.

Je remercie bien M. G. Poupinet (l'ex-directeur de LGIT) et M. M. Campillo (le directeur actuel du labo) pour m'avoir accepté comme un thésard au sein du LGIT.

Je tiens à remercier M. Regnier et le gouvernement français pour m'avoir fourni une bourse en alternance pour mes séjours en France.

Je remerci BHRC (Building and Housing Research Center), l'organisation qui nous a donné la permission d'utiliser les enregistrements accélérométriques de l'Iran.

Je remercie mes amis à Grenoble, et à Téhéran, pour leur soutien (de différents manières); A. Aboura, M. Abtahi, E. Akbari, M. Akbari-Jokar, A. Azadmanesh, A. Baboli, D. Baumont, R. Bousso, P. Buxton, S. Eshghi, M. Farsi, E. Farzanegan, M. Heydari, M.K. Jafari, A. Jalali, C. Lacombe, D. Maclean, G. Mahmoodi, N. Madjoudj, L. Margerin, H. Mirzaei-Alavijeh, K. Pashaei, S. Shakhesi, M. Shirazian, M. Tatar, M. Zaré (mon père!), M. Zolfaghari, F. Zouesh-tiagh,... et les autres dont j'ai oublié les noms!...

Enfin, un grand remerciement à mes compatriotes, pour leur gentillesse et leur coopération avec notre équipe pendant notre manip (1996-1997) de 20000 km de voyage dans mon cher pays.

Que Dieu protège les iraniens et
les autres peuples des pays tributaires des
aléas sismiques... inshaallah!...

Table des matières

20 AOÛT 2003
Univ. J. Fourier - O.S.U.G.
MAISON DES GEOSCIENCES
DOCUMENTATION
B.P. 53
F: 38041 GRENOBLE CEDEX
Tél: 04 76 63 54 27 - Fax 04 76 51 40 58
Mail: ptalour@ujf-grenoble.fr

1 Introduction Générale	5
1.1 Le Risque Sismique en Iran	6
1.2 Problématique	11
1.3 Les Chapitres de ce Mémoire	12
2 Le Catalogue des Mouvements forts en Iran	14
2.1 Introduction	16
2.2 Determination of the Source Data for each Record	17
2.3 Extracting the most Reliable Records	23
2.4 Data Correction	23
2.4.1 Determination of the appropriate frequency band	23
2.4.2 Spectrum shape	24
2.4.3 Filtering and Integration	25
2.5 Site effects	27
2.6 Assigning a Quality Label to each Record	30
2.7 Sources of Errors and Uncertainties	31
2.7.1 Instrumental and macroseismic epicentral distances	31
2.7.2 Focal depths	33
2.7.3 Integration of the filtered records	34
2.7.4 Earthquake intensities	34
2.8 Conclusion	35
3 Les Effets de Site	46
3.1 Introduction	48
3.2 The methodology	49
3.3 An overview on the general situation of the sites and the tests	53

3.3.1	Receiver function method for strong motions	54
3.3.2	Microtremors	56
3.3.3	Geoseismic tests	56
3.4	The results of the geoseismic tests, microtremors and H/V for Strong Motions . .	57
3.4.1	Sites with a satisfactory agreement between the results of the different methods	57
3.4.2	Sites without agreement: failure of the microtremor technique	64
3.4.3	A preliminary conclusion on the results of the different methods	68
3.5	A Site Categorization	69
3.5.1	The Average of Vs for upper 30 meters	71
3.5.2	Discrepancies from the defined criteria	73
3.5.3	Application to all Iranian strong motion data	74
3.5.4	Quality factor for the site determination	74
3.6	Conclusions	75
4	Études particulières: la source sismique et Kappa	80
4.1	Seismic Moment and Stress Drop for the Strong Motion Accelerograms in Iran .	81
4.1.1	Introduction	82
4.1.2	Methodology of the Study: the $\omega^{-\gamma}$ model	82
4.1.3	The sources of Uncertainties	84
4.1.4	Results	84
4.1.5	Application of the method for the records with no reported source	88
4.1.6	Conclusions	94
4.2	Décroissance de l'amplitude à haute fréquence dans le spectre de Fourier de l'Accélération: coefficient Kappa	95
4.2.1	Introduction	95
4.2.2	La méthodologie des calculs de Kappa	96
4.2.3	Les résultats	97
4.2.4	Conclusion	102
5	Durée et Énergie des Mouvements Forts	107
5.1	Introduction	108
5.2	Seismogenic zones in Iran and site conditions	109
5.3	Methodology	111

5.4	Results	114
5.4.1	Comparison of Strong Motion Intervals: 5%-95% and 5%-75%	114
5.4.2	Empirical Relationships for the Strong Motion Duration in Iran	118
5.4.3	Attenuation of a_{rms} and e_a	131
5.5	Conclusions	133
6	L'Atténuation des Mouvements Forts en Iran	141
6.1	Introduction	143
6.2	Methodology	145
6.2.1	The applied approaches	145
6.2.2	Fundamental form	145
6.2.3	Ground Motion Parameters	147
6.3	The input data-base	148
6.3.1	The magnitude values	148
6.3.2	Distance parameter	149
6.3.3	Geological areas	151
6.3.4	Site Categorization	151
6.3.5	Fault mechanism	152
6.4	Results	152
6.4.1	Attenuation coefficients for peak values	153
6.4.2	Attenuation coefficients for spectral ordinates	157
6.4.3	Nonlinear effects in the Iranian strong motions?	168
6.5	Response and Design Spectra for Alborz-Central Iran, and Zagros areas	168
6.6	Conclusions	172
6.7	Régression en une étape	177
6.8	Les études sur la nonlinéarité possible dans les données iraniennes	187
7	Conclusion Générale	198
7.1	Introduction	199
7.2	Catalogue des mouvements forts en Iran	199
7.3	Moment sismique et la chute de contrainte	200
7.4	Études des effets de site	200
7.5	Énergie et durée des mouvements forts en Iran	201
7.6	Atténuation des mouvements forts en Iran	202

7.7 Propositions pour la continuation de ces recherches	202
8 Bibliographie Générale	205
9 Annexes	217

Chapitre 1

Introduction Générale

1.1 Le Risque Sismique en Iran

Le plateau iranien (Figure 1.1) est situé entre les plaques Arabie et Eurasie. Le système structurel en Iran est compressif, et la plupart des failles importantes sont chevauchantes avec des composantes de cisaillement. Les régions sismotectoniques de l'Iran (les plus connues) sont le Zagros au sud-ouest du pays, l'Alborz au nord; l'Iran Central; le Koppeh-Dagh au nord-est; le Makran au sud-est et la plaine du Khuzestan à l'extrême sud-ouest. Les études géologiques de l'Iran montrent que la situation en Azarbayjan (au Nord-Ouest du pays) est plus ou moins similaire aux caractéristiques géologiques de l'Iran-Central. Basé sur les données accélérométriques iraniennes actuellement disponibles, nous allons (au point de vue de la source sismique) distinguer la région de Zagros des autres régions iraniennes (avec des durées et des contenus fréquentiels différents).

La figure 1.2 montre la sismicité récente du plateau iranien. La plupart des séismes destructeurs (récents et historiques) en Iran se sont produits dans les régions de l'Iran-Central et d'Alborz; tandis qu'au Zagros les séismes sont plus fréquents avec des magnitudes de niveau moyen ($M \leq 6$). Les séismes les plus importants en Iran au cours des vingt dernières années sont le séisme de Sarkhun (Bandarabbas) du 7-3-1975 ($M_s 6.1$, $m_b 5.9$); Vendik (Ghaen) du 7-11-1976 ($M_s 6.4$, $m_b 5.8$); le séisme de Khurgu du 21-3-1977 ($M_s 7.0$, $m_b 6.2$); le séisme de Naghan du 6-4-1977 ($M_s 6.1$, $m_b 5.6$); le séisme de Tabas du 16-9-1978 ($M_s 7.3$, $m_b 6.7$, $M_w 7.4$); le séisme de Ghaen du 16-1-1979 ($M_s 6.8$, $m_b 6.0$); le séisme de Korizan (Ghaen) du 14-11-1979 ($M_s 6.6$, $m_b 6.0$); le séisme de Koli-Bonyabad (Ghaen) du 27-11-1979 ($M_s 7.1$, $m_b 6.1$); le séisme de Golbaf (Kerman) du 11-6-1981 ($M_s 6.7$, $m_b 6.1$); le séisme de Sirch (Kerman) du 28-7-1981 ($M_s 7.1$, $m_b 5.7$); le séisme de Manjil du 20-6-1990 ($M_s 7.7$, $m_b 6.8$, $M_w 7.3$); et le séisme de Ebrahimabad (Firouzabad) du 20-6-1994 ($M_s 5.7$, $m_b 5.9$, $M_w 5.9$) [Les épicentres de ces séismes sont indiqués dans la figure 1.2]. La figure 1.3 montre bien que la plupart des épicentres des séismes en Iran sont concentrés dans la région de Zagros en sud-ouest, en Iran-Central (sur les frontières des montagnes et des plaines).

Actuellement, les études sur le risque sismique en Iran se concentrent sur les domaines suivants:

- études néotectoniques et connaissance des failles actives.
- installation d'un nouveau réseau (de sismomètres) [un réseau de stations du WWSSN est installé en Iran depuis fin des années 1950].
- Installation de plus en plus d'instruments de mouvements forts en Iran, et remplacement progressive des instruments analogiques anciens pour des instruments numériques.

- Etudes du mouvement fort en Iran; lois d'atténuation; effets de sites.
- Etudes de microzonage sismique dans les grandes villes (Téhéran, Tabriz, ..etc).

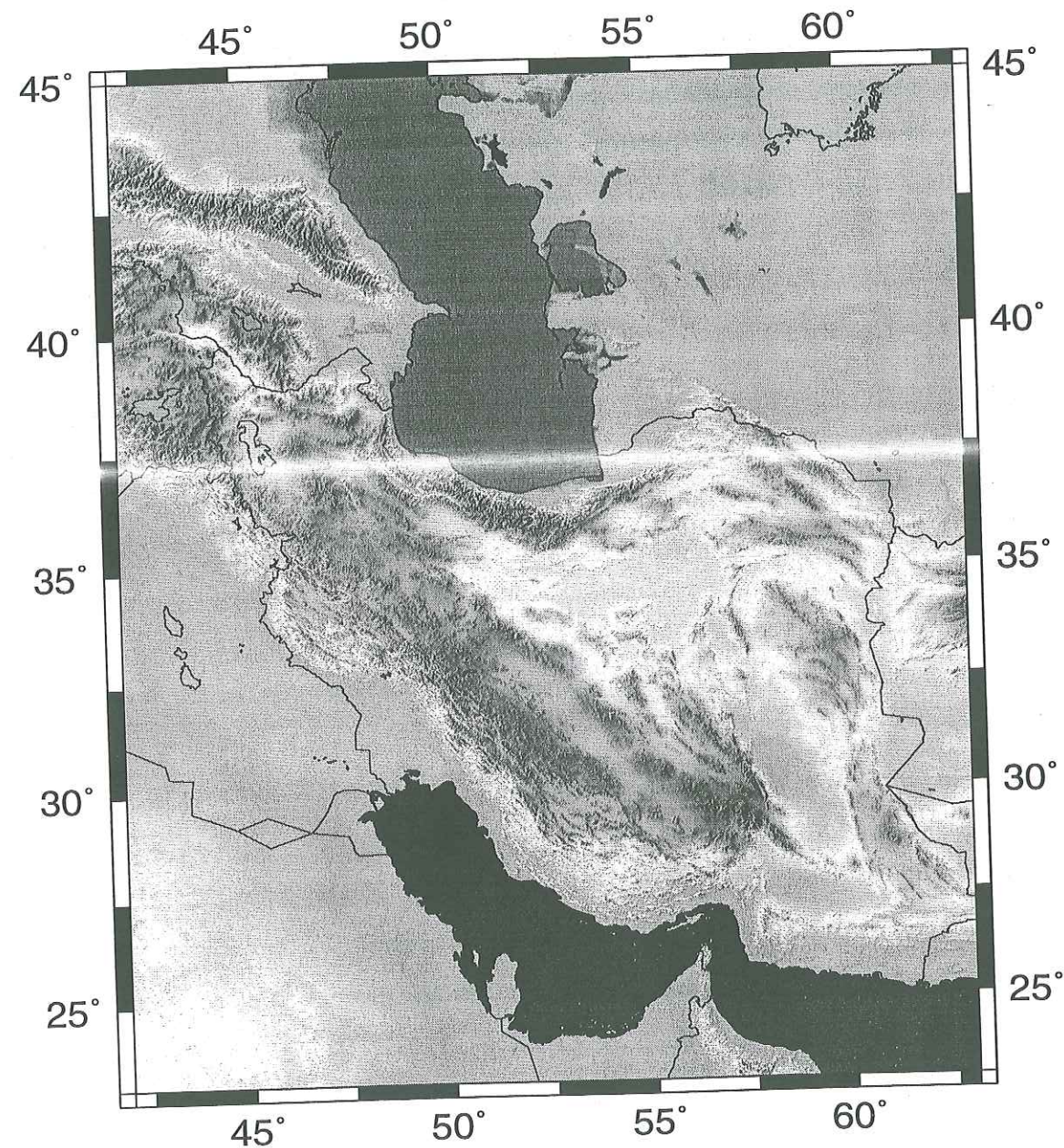


FIG. 1.1 – La carte de la topographie du plateau iranien et des territoires voisins.

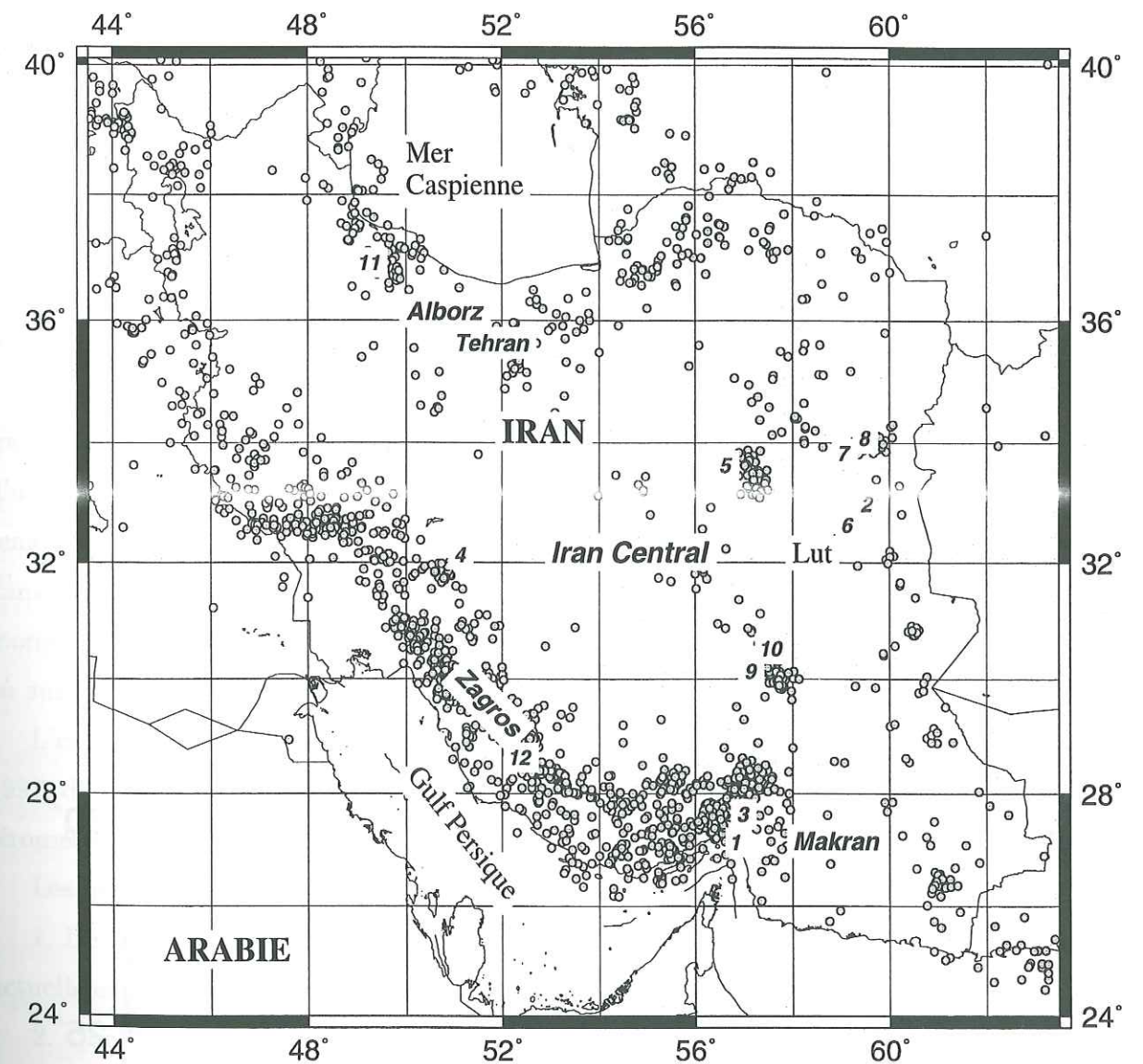


FIG. 1.2 – Les séismes en Iran avec les magnitudes supérieurs à 4.5 de 1965 à 1998; les chiffres sur la carte montrent les épicentres des séismes de 1: Sarkhun, 2: Vendik, 3: Khurgu, 4: Naghan, 5: Tabas, 6: Ghaen, 7: Korizan, 8: Koli, 9: Golbaf, 10: Sirch, 11: Manjil, 12: Ebrahimabad; pour plus de détails regardez le texte.

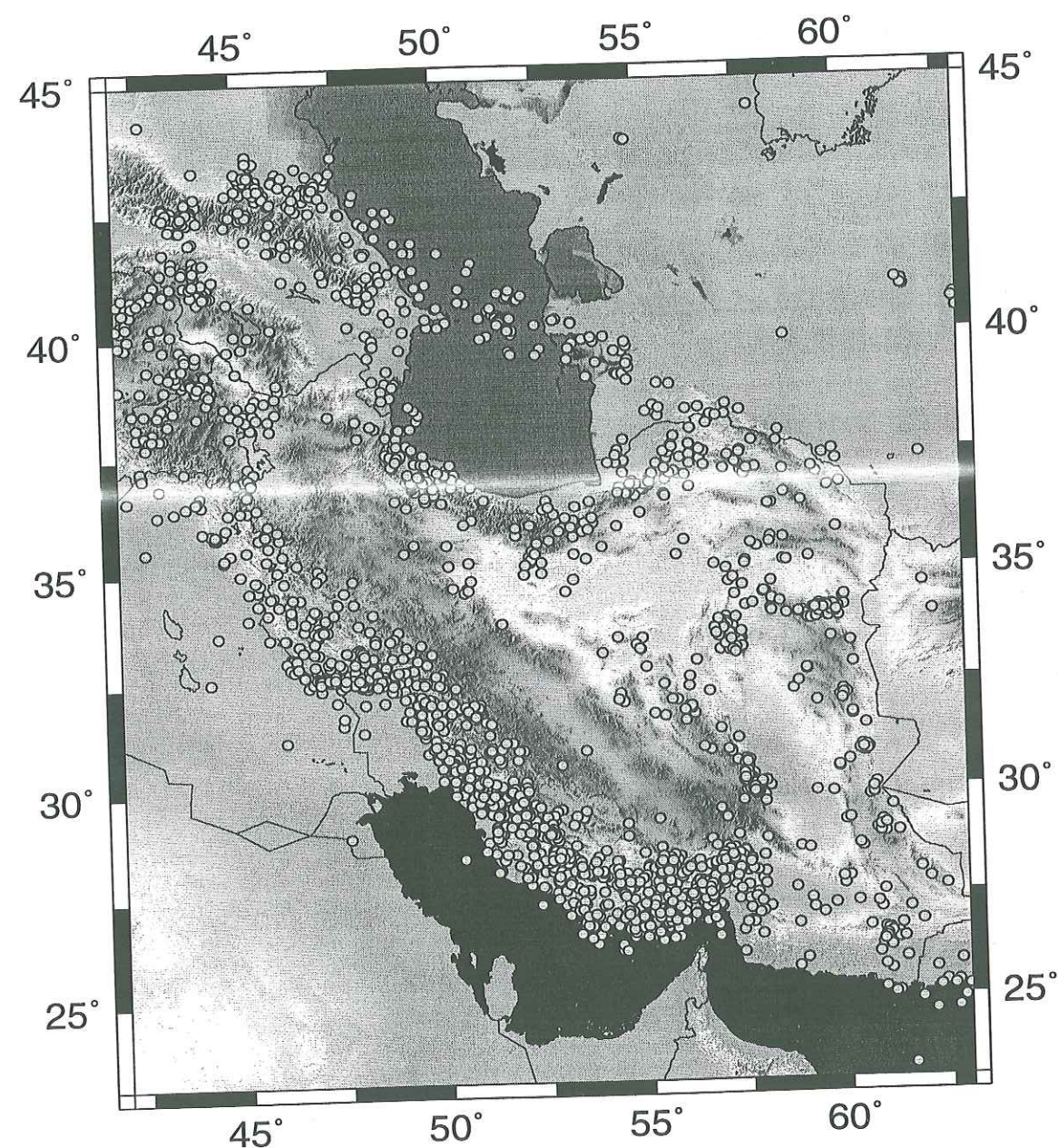


FIG. 1.3 – Les séismes en Iran avec les magnitudes supérieurs à 4.5 de 1965 à 1998, sur fond topographique

1.2 Problématique

Le risque sismique a du être pris en compte en Iran pour les nombreux projets de constructions d'ouvrages majeurs en Iran (barrages, ponts, villes nouvelles, tours, constructions souterraines comme les tunnels, le métro de Téhéran et des autres grands villes,... etc.) depuis une vingtaine d'années. Tout ces études se sont déroulées en estimant les sollicitations de dimensionnement sur la base d'enregistrements et/ou de modèles d'atténuations des mouvement forts développés dans d'autres régions du monde (Californie, Japon ou Europe) (Zaré 1995). Il y avait toujours cette discussion sur l'application des loi d'atténuations: est-il possible d'extrapoler une relation d'atténuation développée sur la base des données accélérométriques d'une certaine région? Les spécifications sismotectoniques et physiques différentes de la croûte de chaque région (épaisseur, facteur de qualité, contraintes principales, géologie ...etc) imposent certaine limites à de telles extrapolations. Ce type d'études du risque sismique, sans avoir utilisé les données iraniennes et des modèles basés sur ces données, n'arrivent jamais à manifester l'aléa sismique d'une façon optimum en Iran. Néanmoins, on pense que les analyses du risque sismique en Iran, tenant compte de ces résultats, peuvent être plus réalistes. Les études qui seront présentées dans ce mémoire sont donc d'un intérêt fondamental parce qu'un séisme destructeur, à toute moment ou l'autre, même quand quelqu'un lit ce texte!, peut se produire quasiment n'importe où sur le plateau iranien (l'Iran et ces régions voisins).

L'existence d'un réseau accélérométrique en Iran depuis 1975 (avec 1000 stations à la fin 1997, d'après un rapport du BHRC) permet une étude spécifique en utilisant les données accélérométriques iraniennes.

Les questions importantes auxquelles on voudrait répondre dans cette thèse sont:

1. De combien d'enregistrements accélérométriques de bonne qualité dispose-t-on à l'heure actuelle en Iran?
2. Quels sont les effets de site dans les données iraniennes? Combien de "classes de site" différentes doivent (ou peuvent) être prises en compte?
3. Quelles sont les caractéristiques de source des séismes destructeurs que l'on peut étudier à partir des enregistrements accélérométriques iraniens (moment sismique, chute de contrainte, processus ... etc.)?
4. Est-il possible de distinguer à l'intérieur de l'Iran différentes zones géographiques ou tectoniques, ayant des comportements différents en matière de mouvement forts?
5. Quelles sont les variations de l'énergie et de la durée des mouvements forts dans différentes régions de l'Iran?

6. Quels sont les paramètres d'atténuation en Iran, et quel est le meilleur modèle pour arriver aux résidus minima?

1.3 Les Chapitres de ce Mémoire

Ce mémoire comporte neuf chapitres différents :

- Le deuxième chapitre est consacré au catalogue des mouvements forts iraniens : 770 enregistrements accélérométriques iraniens ont été étudiés. Les rapports signal sur bruit ont été calculés pour tous les enregistrements iraniens disponibles. Un filtrage passe-haut et passe-bas est effectué pour éliminer les bruits et les signaux trop bruités. Les caractéristiques des sources sismiques (localisation, magnitude) ont été trouvées pour les enregistrements de qualité convenable, essentiellement à partir des bulletins des organismes sismologiques internationaux, et aussi, chaque fois que c'était possible, des informations locales. Le catalogue présenté dans ce chapitre est composé de 279 données accélérométriques 3 composants, analogues et numériques.

- Le troisième chapitre est consacré à l'étude des effets de sites. Cinquante sites ont d'abord fait l'objet d'un examen attentif, avec la réalisation des mesures géotechniques ou géophysiques spécifiques. 25 sites ont été l'objet de plusieurs types de mesures simultanées : sismique réfraction de surface, profil géotechnique, bruit de fond sismique, tandis que les 25 autres sites faisaient l'objet exclusivement de mesure de bruit de fond sismique. Les résultats de ces mesures ont été comparés à ceux de l'analyse du rapport H/V des enregistrements accélérométriques, et ont conduit à proposer une nouvelle classification en 4 catégories, sur la base du seul rapport H/V. Cette classification s'avère être assez bien corrélée aux valeurs de V_s dans les 30 premiers mètres.

- Le quatrième chapitre se compose d'études sur le moment sismique, la chute de contrainte et la décroissance haute fréquence. Pour un nombre importants d'enregistrements numériques aucune information locale ou télé-sismiques ne permet de correspondance avec un événement dûment répertorié. Les magnitudes de moment (M_w) ont donc été calculées pour toutes les données (y compris les enregistrements figurant dans les bulletins des organismes internationaux). Les distances hypocentrales ont été estimées par les différences entre les temps d'arrivée des ondes P et S (quand c'était possible). Le calcul de M_w a fourni un échelle de magnitude, homogène, pour toutes les données. La distance hypocentrale est la seule définition pour les données iraniennes qui peut être à peu près contrôlée avec les données accélérométriques. Ce faisant, avec ces calculs de magnitudes et de distances hypocentrales, 189 données trois composantes ont pu être ajoutées aux 279 enregistrements précédents. D'un autre côté, un ordre de grandeur

pour les chutes des contraintes a pu être estimé, et on observe qu'elles sont représentatives de séismes intra-plaque.

- Le cinquième chapitre est consacré au calcul de l'énergie, de la durée des mouvements forts, et de l'accélération moyenne (A_{rms}) et à l'établissement de lois d'atténuation sur ces différents paramètres.

- Le sixième chapitre présente les lois d'atténuation sur les principales caractéristique des mouvements forts, à savoir les valeurs maximales et les valeurs spectrales. Plusieurs formes fonctionnelles ont été analysées, et les régressions ont été établies aussi bien en 1 seule étape qu'en 2 étapes. Les paramètres de ces lois sont présentés pour deux régions du pays (qui semblent montrer des comportements accélérométriques différents) et pour l'ensemble les données iraniennes.

- Le septième chapitre présente un bilan général de ce mémoire. Des suggestions sont formulées pour continuer ce type d'études en Iran et dans les pays voisins.

- La bibliographie générale et l'annexe sont placées dans le huitième et le neuvième chapitres, respectivement.

Les études sur les mouvements forts en Iran présentés dans ce mémoire, constituent un premier pas pour établir en Iran les bases de la « sismologie de l'ingénieur » (Engineering Seismology), un des points très importants pour améliorer la conception parasismique dans ce pays. Cette amélioration sera à la base de toute mise-à-jour des codes parasismiques en Iran.

Chapitre 2

Le Catalogue des Mouvements forts en Iran

Résumé Les données accélérométriques en Iran seront étudiées dans ce chapitre et présentées dans un catalogue qui comprend les valeurs maximales des mouvements forts et les caractéristiques des sources pour chaque enregistrement. Les enregistrements sont les données pour lesquelles : 1) La qualité de l'enregistrement et de la numérisation (pour les données analogiques) est suffisamment bonne et 2) les caractéristiques de la source auront pu être déterminées à partir des enregistrements télésismiques. Les enregistrements de mouvements forts en Iran sont de deux types: les données analogiques qui sont obtenues par les instruments SMA-1 (Kinematics), et les données numériques enregistrées par les appareils SSA-2 (de même marque). D'après les rapports du BHRC (l'organisation qui s'occupe de réseau accélérométrique iranien) il y avait, à la fin de l'année 1997, 1000 stations installées un peu partout en Iran. Parmi environ 750 enregistrements disponibles (obtenu entre 1974 et 1997), on a choisi 279 enregistrements (qui satisfont les conditions précédentes), dont 169 analogiques et 110 numériques (en trois composantes). Ces données proviennent des différentes régions du pays: 143 du Zagros (ouest et sud-ouest), 78 de l'Iran-Central, 48 de l'Alborz (au nord), 9 de l'Azarbayjan (au nord-ouest) et 1 enregistrement du Koppeh-Dagh (en nord-est). Nous allons donc présenter le premier catalogue de mouvement forts en Iran, qui contient les noms des stations, la catégorie du site, les fréquences de filtrage, les valeurs maximales de l'accélération, de la vitesse et du déplacement, les paramètres de la source [la magnitude (M_s , m_b , M_w , M_L)], les distances à la source (épicentrale, hypocentrale, et distance à l'épicentre macrosismique), l'intensité, le mécanisme au foyer quand celui-ci était disponible, et un indice de qualité pour chaque enregistrement présenté dans ce tableau.

The Iranian Accelerometric Data Bank, A Revision and Data Correction

Mehdi Zaré, Pierre-Yves Bard and Mohsen Ghafory-Ashtiany

Article publié dans le "Journal of Seismology and Earthquake Engineering", Vol.1, No.1, pp.1-22

Abstract The Iranian strong motion records are studied in order to prepare a catalog to be used as a data base for further studies (for instance empirical attenuation laws). The network was installed in 1974, and now comprises 1000 stations. The instruments are SMA-1 analog (installed before the Manjil earthquake) and SSA-2 digital Kinematics types (after Manjil

earthquake). Out of a total of 450 records with a priori satisfactory quality (well recorded and correctly digitized in the case of the SMA-1 records), a set of 279 records was selected for which it was possible to associate correctly determined source parameters (source magnitudes and epicentral distances): 169 correspond to SMA-1 instruments, and the remaining 110 to SSA-2. The distribution of the records in the different geological/seismotectonics regions are; 143 in Zagros, 78 in Central-Iran/Lut, 48 in Alborz, 9 in Azarbayjan and one record in the Kopeh-Dagh region. The main outcome of this paper is to provide the first strong motion catalog of Iran, with the indication of the site conditions; the frequency band of the reliability of the records, the peak values of acceleration, velocity and displacements, the source parameters (magnitude, epicentral and macroseismic distances), the intensity and finally the fault plane solutions whenever possible.

2.1 Introduction

The first Iranian strong motion instruments were installed in 1974. The strong motion network has grown considerably since that time and by the end of 1997 comprises 1000 stations all over Iran, in different geologic conditions. The first instruments were of Kinematics SMA-1 type. The SMA-1 analog recorders have been in use from 1974 until 1991 (the great Manjil earthquake and its aftershocks provided the last important records on SMA-1 instruments). They have been progressively replaced by SSA-2 instruments after the Manjil (1990) earthquake in NW Iran. By the end of December 1997, 640 SSA-2 and 200 SMA-1 instruments were installed mostly in free-field conditions while 58 SSA-2 and 2 SMA-1 instruments were placed on dams all over the country. Several hundred of records have been obtained with this network.

The total number of records (three component accelerograms) which were available for this study were 770 (out of which about 550 SMA-1). These data were distributed by the Building and Housing Research Center of Iran (BHRC) as uncorrected but digitized records. The raw data set distributed by BHRC comprises a relatively complete data set of recordings obtained by the national accelerometric network of Iran since 1974, otherwise we have used some BHRC previously corrected data in order to complete some gaps in the recent data set. Recent records (most of them in the southern Iran; Zagros area) were obtained with the digital network. The digital records are obviously more reliable than the previous analog ones; they include the exact trigger time, and there is no more additional noise brought in by the handy digitalization process. Therefore the amount of reliable SSA-2 accelerograms selected here after about two years (1994-1995) almost equals the number of well-recorded SMA-1 records, although they

relate to a much larger duration; about twenty years (1974-1993).

The previous publications on the Iranian accelerometric data are limited to some reconnaissance reports on the great earthquakes, comprising the uncorrected accelerograms or just the peak values (e.g. Moinfar and Eetemadi, 1982, Moinfar and Adib-Nazari, 1982, Moinfar and Naderzadeh, 1990, Niazi and Bozorgnia, 1992) and the reports presenting a list of the recorded uncorrected accelerograms (BHRC, 1992) or a preliminary processing of the records of one particular event (Moinfar and Shoja-Taheri 1988). The complete listing of the Iranian analog data has been published in 1993 by BHRC, and the SSA-2 accelerograms are published gradually. Some studies on some particular subsets have been already published by Niazi (1986), Shoja-Taheri and Anderson (1988), and Saikia (1994) on the Tabas earthquake of 1978 and in Zaré (1996) on Tabas (1978) and Manjil (1990) earthquakes. Preliminary attenuation studies in Iran have been already performed by Zaré (1995) who has presented the models, developed based on some accelerograms recorded during the great earthquakes in Iran. In another the Iranian data have been compared by the American models is performed by Niazi and Bozorgnia (1990).

The scope of this study was to sort and select accelerograms within this large data set, so as to propose a catalogue of strong motion data in Iran with appropriate and valuable source parameters and site conditions. This catalog (Appendix 1) is the first one to present the well recorded accelerograms in Iran. The catalogue comprises the source and site parameters as well as the maximum values of acceleration, velocity and the displacement for each record. A quality factor is defined as well in this table to indicate the level of reliability of each record.

It should be noticed that during the final stages of the present study, another great earthquake with a magnitude over 7 has shocked the eastern Iran region (Abiz - Ghaen - earthquake of 10 May 1997, Mw7.3) but the recent records from this earthquake were not yet accessible to be included in this study.

In this paper we will present, first, how we have determined the source parameters for each record. The method to select the best (best recorded, more reliable,...) records are explained afterward, and then our methodology to process the accelerograms are presented. The sources of the probable errors are discussed finally.

2.2 Determination of the Source Data for each Record

We have chosen a set of 279 records within which we could find minimum source parameters (source magnitudes and epicentral distances) and the best qualities. The selected SMA-1 and SSA-2 accelerographs are shown in Figure 2.1. Figures 2.2 to 2.5 show the distribution of

the accelerometric sites and the instrumental epicenters of the recorded events in the national network, in the northwest, northeast, southwest and southeast of Iran, respectively.

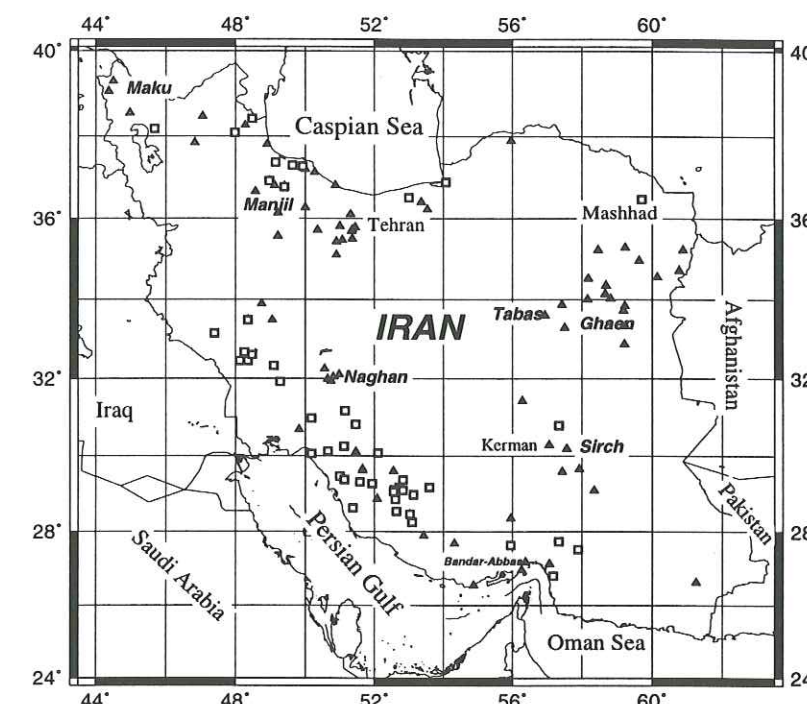


FIG. 2.1 – The locations of the selected accelerometric sites in Iran in this study; the triangles show the analog SMA-1 and quadrangles show the digital SSA-2 instruments.

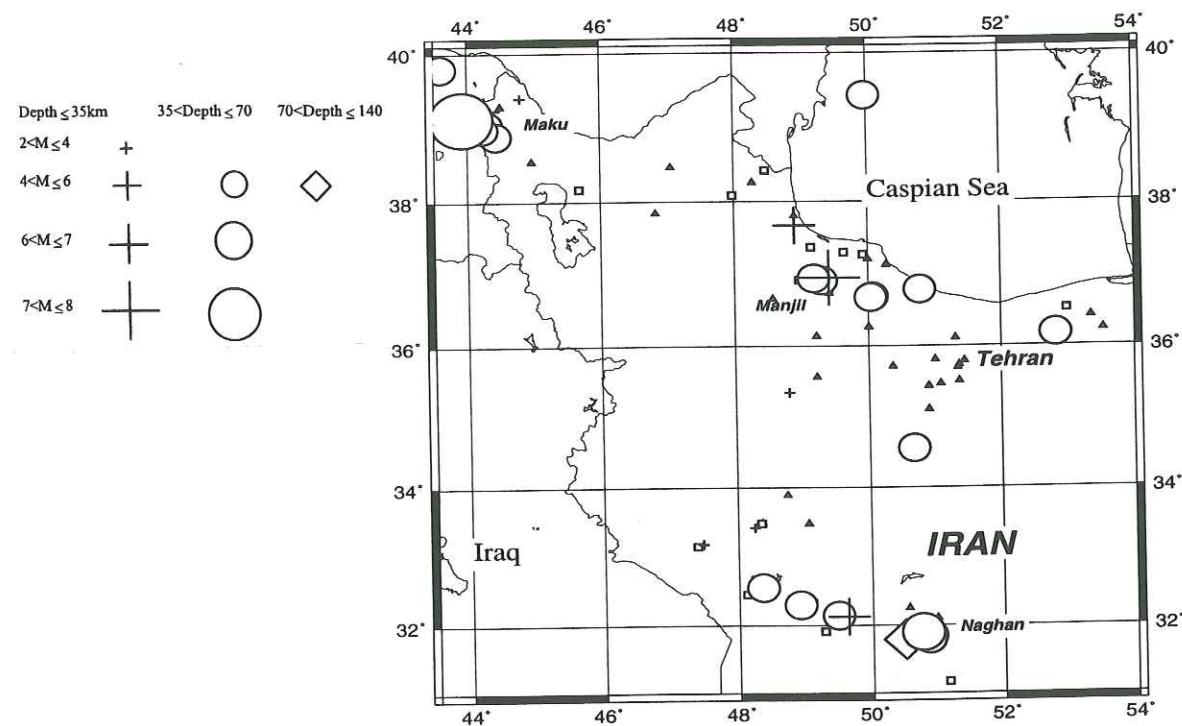


FIG. 2.2 – The location of the strong motion station and the epicenter of the event which a re recorded in these stations in northwest of Iran.

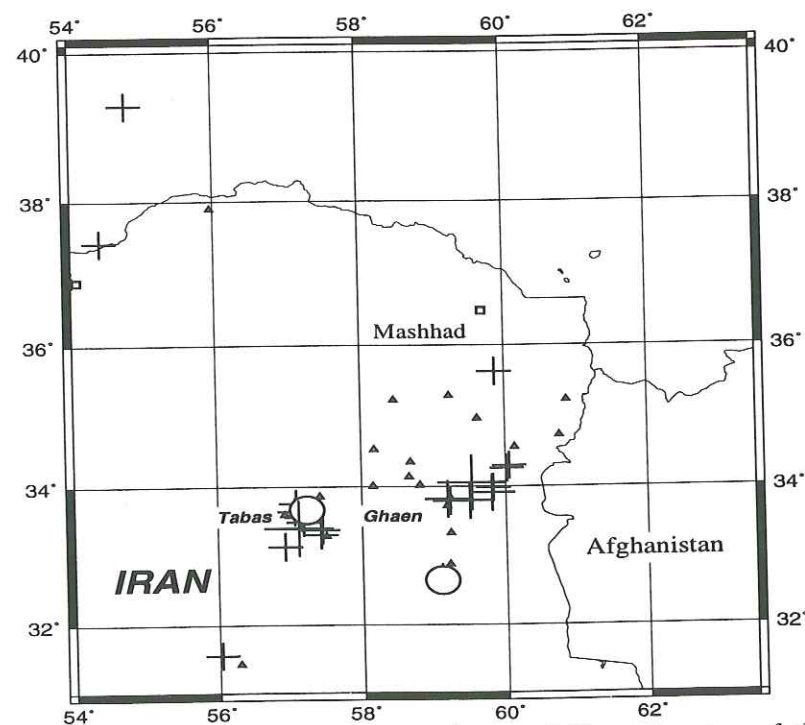


FIG. 2.3 – The location of the strong motion station and the epicenter of the event which a re recorded in these stations in northeast of Iran.

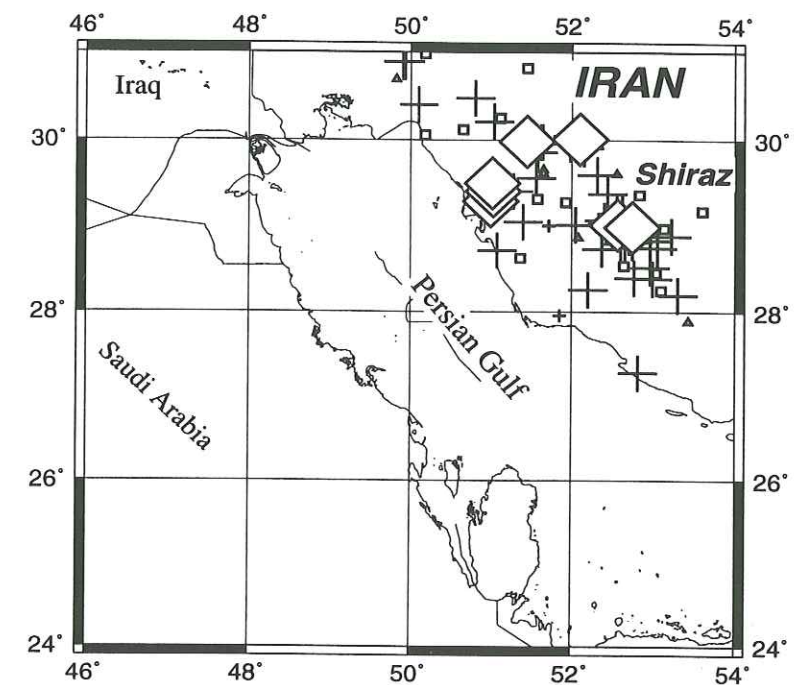


FIG. 2.4 – The location of the strong motion station and the epicenter of the event which a re recorded in these stations in southwest of Iran.

Most of the accelerometric data have been disseminated without corresponding earthquake characteristics (location and magnitude) for each record. Based on the existing data for each record (the peak accelerations, the date and arrival times of the SSA-2 records, or the date of the visit of the operators to change the analog films of the SMA-1 instruments) the causing earthquake is determined. The epicentral locations determined by NEIC and ISC are used in most of the cases. Meanwhile, reports by the national seismic network (Institute of Geophysics, Tehran university; IGTU) and earthquake reports published in the national dailies (if available) are analyzed to check the localities of the macroseismic areas and therefore to have other criteria to check the epicentral distances. Whenever reports on macroseismic epicenters could be found (Ambraseys and Melville 1982; Zaré 1991; 1994; Zaré and Moinfar 1994; Heydari and Zaré 1995; or therefore detail of damage reports in the dailies, or in the NEIC or ISC monthly bulletins) it was possible to have an estimation of the epicentral distances (Appendix 1).

The magnitude of the events are presented as available; the body wave, surface wave and moment magnitudes (m_b , M_s and M_w , reported by NEIC and ISC) are included, whilst the local magnitudes are given, when available, in the reports by the national seismic network (IGTU).

The focal depths show that most of the recorded events in the Iranian plateau were super-

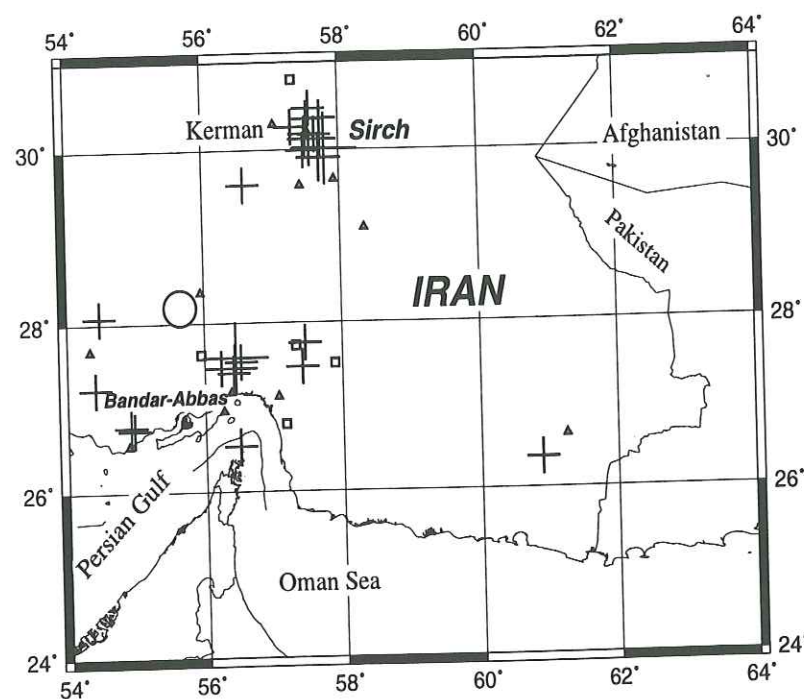


FIG. 2.5 – The location of the strong motion station and the epicenter of the event which a re recorded in these stations in southeast of Iran.

ficial. Most of the events had focal depths between 0 and 35 Km (218 records; comprising the depths which are reported '33km', that are the defaults to show the superficial events when it was not possible to determine an exact depth). Forty-one other events have a depth between 35 and 70 Km (in the Zagros area, Alborz, northern Lut, and Azarbayjan - NW Iran - region). Six have a depths between 70 and 140 Km (on the Zagros thrust zone, Southern Zagros and Alborz). There was no depth reported for 12 other events.

The earthquake intensities presented in this work are based on the reported isoseismal maps (Ambraseys and Melville, 1982; Ambraseys, 1988; Berberian et al, 1984; Eshghi et al, 1994; Moinfar and Naderzadeh 1990), but in some cases an estimated intensity was added based on detailed reports that were found in dailies. The intensity values are all presented in MSK scale: when they were reported in another scale, they were converted to this scale using a comparison chart for different intensity values (Japan Technical Committee 4, 1992). The intensity may give an idea of the damage or shaking of an event in an inhabited region. In some cases the landslide reports (as geotechnical evidence) are also used to estimate the intensity; a previous study on the Manjil earthquake (Zaré 1993) has shown that landslides in the form of rock-block slides occurred only in areas with intensities of at least VI MSK. The localities of the most important macroseismic regions, localized in this study, are shown in Figure 2.6. A summary

on these localities is given in Appendix 2.

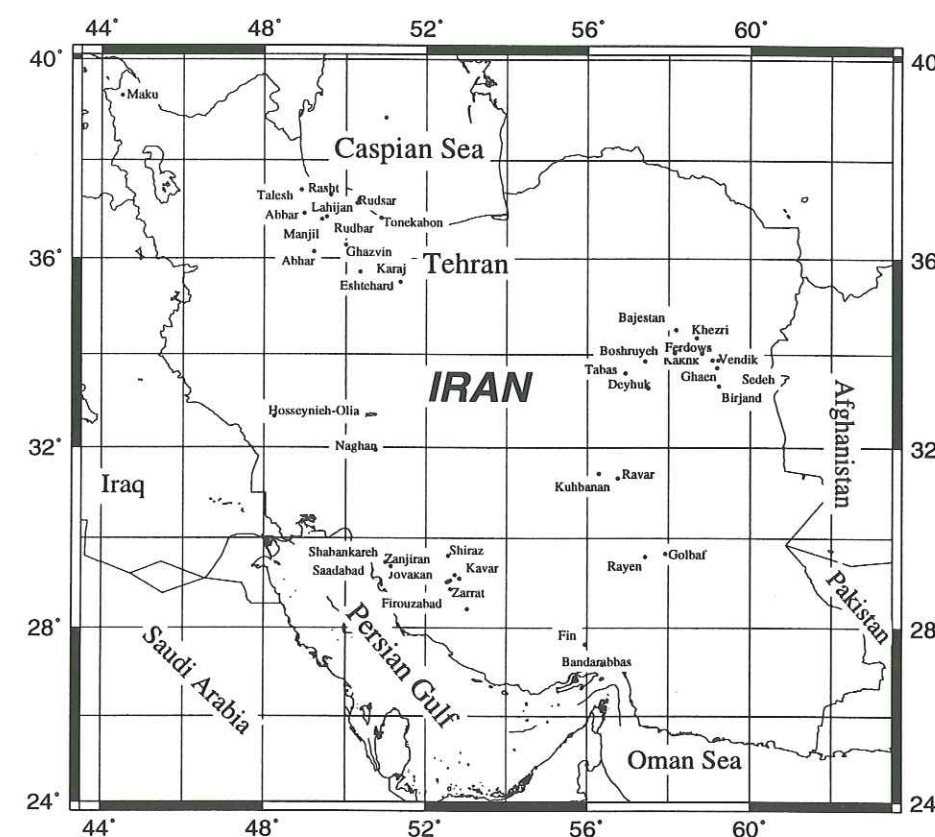


FIG. 2.6 – The selected stations in this study.

The focal mechanisms are reported in Appendix 1 based on the NEIC monthly publications 'Preliminary Determination of Epicenters' as well as the monthly bulletins of ISC. The data presented with reported focal mechanism number 100, of which 40 have strike-slip/reverse solutions, and 31 pure strike slip, 24 pure reverse, 4 pure vertical plane and just one with strike-slip/normal mechanism. Most of the events thus have a strike-slip/compressional mechanism, in agreement with the recent general tectonic activity in the Iranian plateau (by compression between the Arabian plate, in the southwest, and the Turan -Eurasian- plate in its northeast). The deformation is accommodated through the strike-slip and reverse/thrust faults in most of the cases in this plateau. Jackson and McKenzie (1984, 1988) have shown the details of such features of stress and deformation in the Iranian plateau.

2.3 Extracting the most Reliable Records

The criteria to select the records are presented below: . Knowledge of the magnitude and source location. The existence of the minimum required source parameters (magnitude and epicentral distance) was necessary to develop the attenuation laws. . Acceptable signal to noise ratio (for the SMA-1 data). Many SMA-1 records had long period noises. The magnitude of the noise was such that it was not possible to distinguish real signal from the noise (especially in the case of the records corresponding to the low magnitude events or the records that were obtained in the far distances from the epicenters).

The amount of low and high frequency noise was verified through the signal to noise ratios. This ratio was calculated for each records. The way to calculate this ratio is described further below.

2.4 Data Correction

The data correction (after base-line correction) is carried out through the following steps:

2.4.1 Determination of the appropriate frequency band

For each record, the Fourier transform of the signal is computed $S(f)$ over a length t_s , as well as the Fourier transform of the noise, computed over a length of t_n . The normalized signal to noise ratio $N(f)$ may be shown as :

$$R_{sn} = \frac{\frac{S(f)}{\sqrt{t_s}}}{\frac{N(f)}{\sqrt{t_n}}} \quad (2.1)$$

The threshold level of 3 for R_{sn} is selected to delimitate the frequency band where the information is meaningful. The example of Bandarabbas record during the Sarkhun earthquake of March 7, 1975 (Ms6.1, mb5.9) that is recorded at an epicentral distance of 28 km (Appendix 1, Figure 2.7) is selected to show the procedure of the correction. This three component accelerometer (raw data) is shown in Figure 2.7 as it results from the digitalization. The window of 30 to 45 sec is selected for noise window $N(f)$, and the window between 0 to 25 sec is chosen for signal window $S(f)$. The R_{sn} ratio for this record is presented in Figure 2.8. A part of this spectrum between 0.6 and 20 Hz may be selected as the proper signal frequencies. This

procedure may be too severe when there is no clear « noise » window over the whole record length.

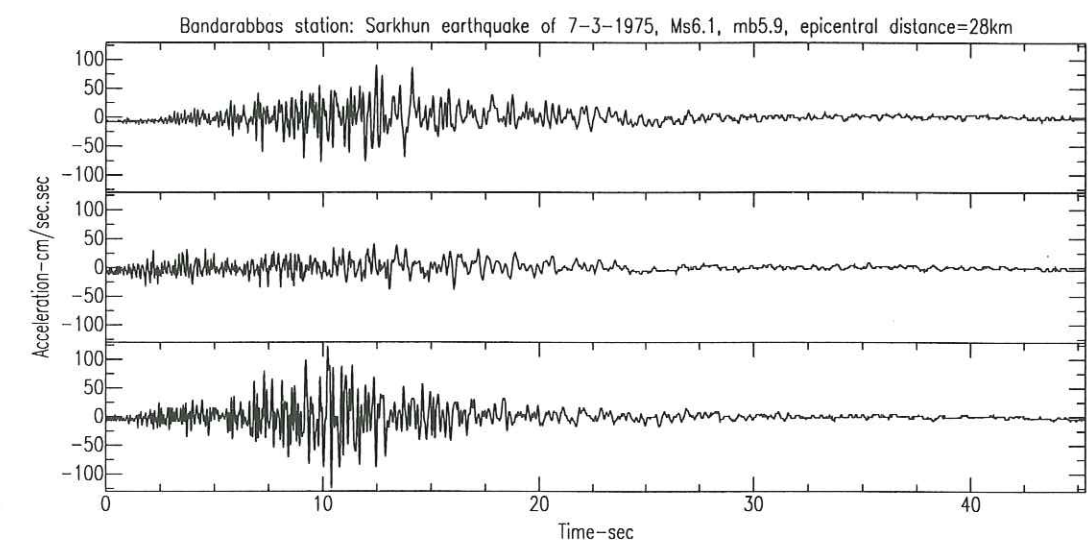


FIG. 2.7 – Three component acceleration time history of Sarkhun earthquake (7-3-1975) recorded in Bandarabbas (before correction and filtering). The middle record is the vertical and the two others are the horizontal components.

2.4.2 Spectrum shape

To be sure that the frequency band selected is the dominant signal band, the Fast Fourier Transform (FFT) is calculated for all the records. The FFT for the three components of the aforementioned record is presented in Figure 2.9. According to the ideal shape of the FFT for acceleration, an f^2 shape is expected in the area below the « corner frequency » f_c and a decaying shape at high frequencies beyond « maximum frequency » f_{max} . A more or less constant amplitude of the FFT spectrum (below f_c) or at high frequencies (beyond f_{max}) estimates some low or high frequency noises. In Figure 2.9, the part of the spectra before 0.6Hz and after 20Hz are abnormally high. However these trends might be continued and descend in the ideal slopes in these areas. Therefore these parts may be thought of as noises and the section between these two limits contains the reliable signal. As is shown in this example, the accuracy of the selected

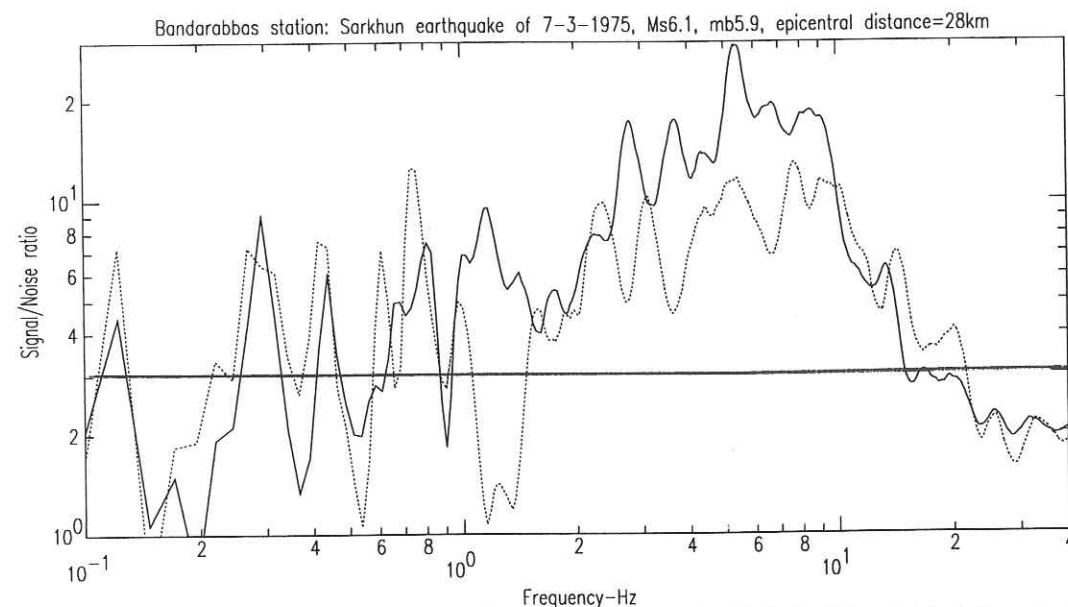


FIG. 2.8 – The signal to noise ratio for the time history in fig 2.7. The dotted line is the spectrum for the vertical and the continuous line is for the horizontal components.

windows for the noise and signals, as well as the applied method of signal to noise ratio is verified by checking the spectral shape.

2.4.3 Filtering and Integration

Once the reliable frequency band is determined through both signal to noise ratio R_{sn} and checking of the spectrum shape, the SAC (Seismic Analysis Code) software is used to filter the records in those frequency bands with infinite impulsive response (IIR) filters. The butterworth filter is applied in the present study. This type of filters is a good choice since it has a fairly sharp transition from pass band to stop band, and it has a moderate group delay response. The result of the use of band-pass filtering is shown in Figure 2.10 in the case of Bandarabbas accelerograms during the Sarkhun earthquake. The FFT for this three component record after the filtering (using a band-pass filter with cutoff filters 0.6 and 20 Hz) is presented in Figure 2.11.

The high-pass filters have also been used to eliminate the low frequency (long period) noises from the digital (SSA-2 Kinematics) records although this filter is much less important than for SMA-1 records. For instance, Figure 2.12 shows the three components accelerograms in the

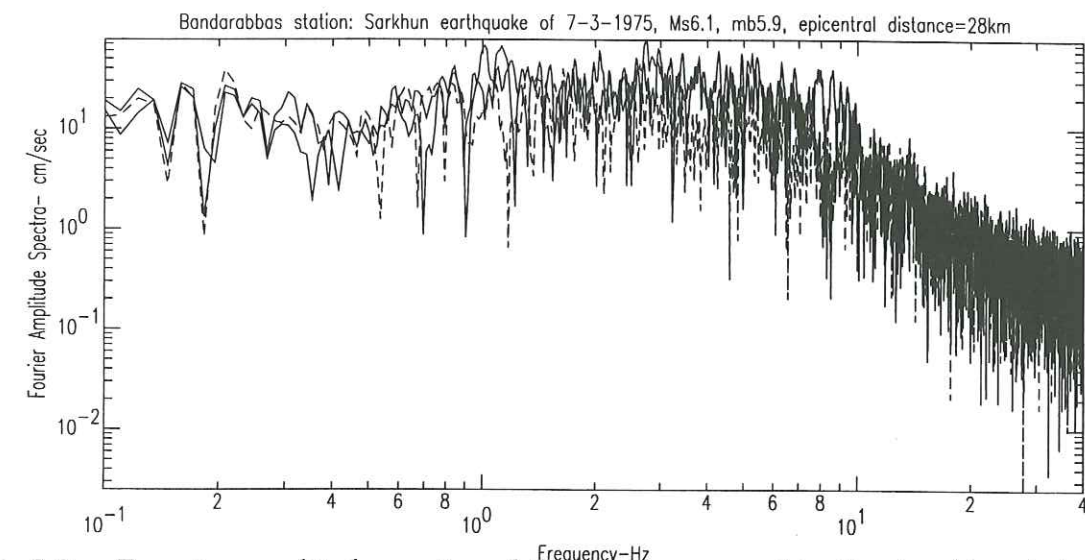


FIG. 2.9 – Fourier amplitude spectra of the Sarkhun record in Bandarabbas, before filtering. The dotted line is the spectrum for the vertical component.

Zanjiran station recorded during the Ebrahimabad earthquake of 20-6-1994. This is the record with the highest acceleration (among the digital records); peak acceleration exceeds 1g. In these cases there were no handy digitalization noises, therefore the filters were selected on the basis of the Fourier spectra to see in which part(s) the FFT spectra differed from the ideal forms before the corner frequency f_c and after the maximum frequency f_{max} . These digital recordings have only very small high frequency noise which does not affect significantly peak values (the high frequency noises are generally in the domain of 50 to 100 Hz). Therefore the main attention must be paid to the low frequency noises which are evident before the corner frequency f_c . The low frequency noises may cause the greatest divergence on the velocity time-histories after an integration on the acceleration time-history. The domain of the low frequency noises may be searched for the example of Figure 2.12 by taking a FFT (shown in Figure 2.13). Even in these transformations some low frequency noises may be seen below 0.3 Hz. Applying a high-pass butterworth filter of 0.3 Hz, one may get the FFT given in Figure 2.14. The filtered acceleration time history is shown in Figure 2.15. The integration on this record after filtering (Figure 2.16) indicates no divergence from the base-line and so a proper filter is selected. The same high-

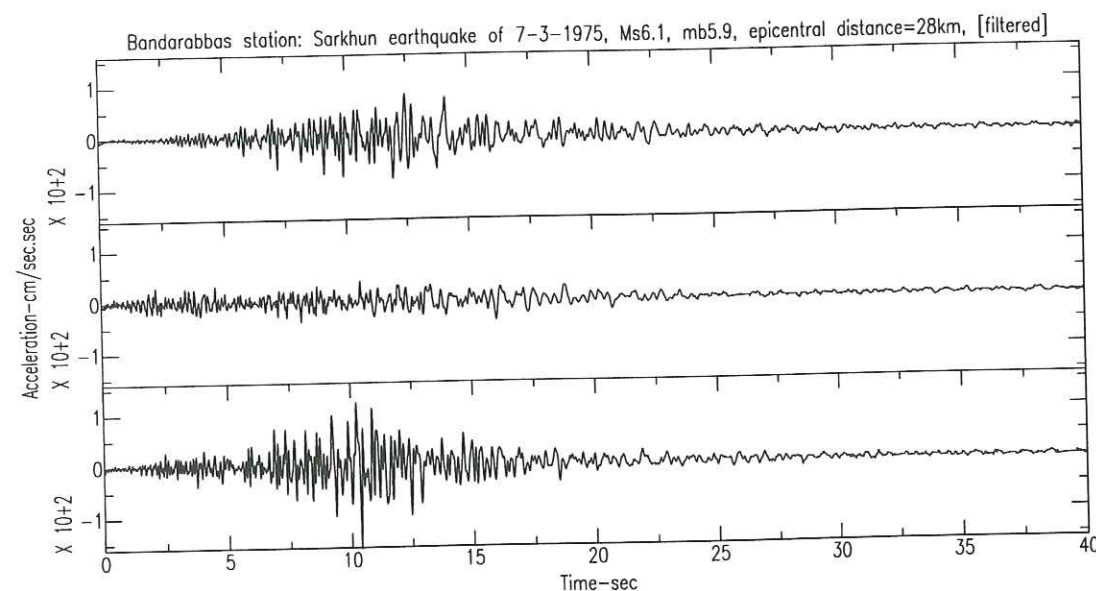


FIG. 2.10 – The corrected and filtered three component acceleration time history in Bandarabbas. The middle record is the vertical and the two others are the horizontal components.

pass filter (0.3 Hz) is applied before the second filtering (on the velocity time-history) and the resultant displacement time-history is shown in Figure 2.17.

The analog corrected record (after filtering) has been integrated to find the velocity and displacement time-histories (Figure 2.18 and 2.19, respectively). It is noteworthy to say that in the present case (Sarkhun earthquake record in Bandarabbas) there was no need to use another filtering before the second integration (to obtain the displacement time-history). As shown in Appendix 1, in most cases a second filtering was needed to obtain the displacement spectra starting and ending on the zero base-line, and with no sharp offset when the recorded samples meet the zero baseline. When these abnormal forms are observed, a second filtering is applied to eliminate these effects.

2.5 Site effects

The records are obtained under different soil conditions. As there are no downhole arrays in the country nor any pair of sites in one locality, in most cases there is no possibility to compare

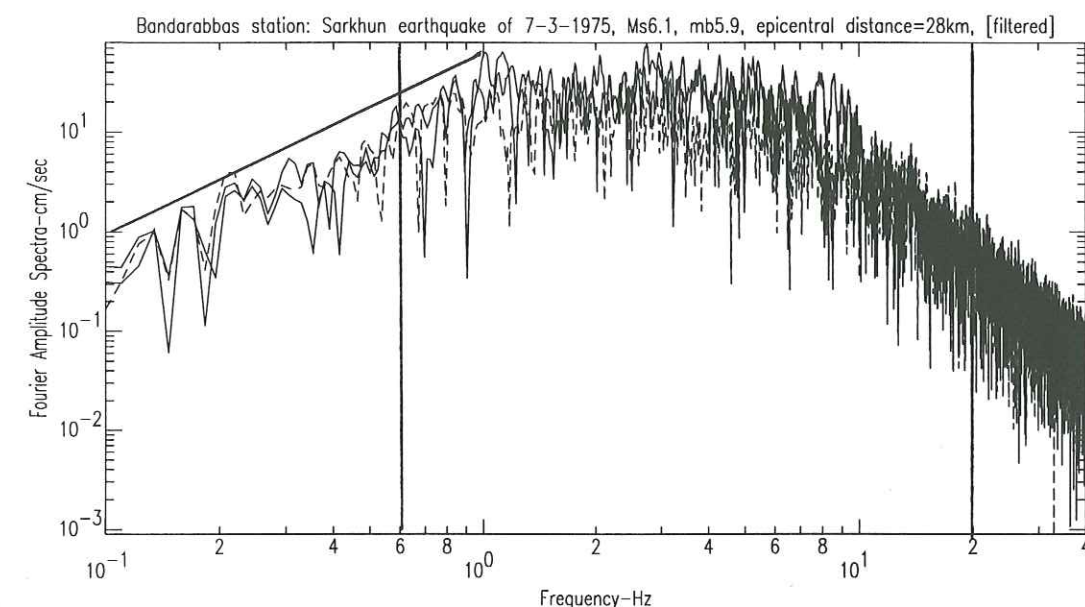


FIG. 2.11 – Filtered Fourier amplitude spectra of the Sarkhun record in Bandarabbas. The dotted line is the spectrum for the vertical component.

empirically the records on soil and on nearby rock outcrops.

Soil conditions are also indicated in Appendix 1. These soil categories were defined after a comprehensive study of soil conditions which is detailed in another paper (Zaré et al 1999a). In brief, site category 1 corresponds to rock and hard alluvial sites, with $V_s > 800$ m/s over 1st 30m depth and site amplifications (SAM) over 15 Hz. The site category 2 relates to alluvial sites; thin soft alluviums, with $500 < V_s < 700$ over 1st 30m depth, and $5 < \text{SAM} < 15$ Hz. The site category 3 corresponds to soft gravel and sandy sites, with $300 < V_s < 500$ over 1st 30m depth and $2 < \text{SAM} < 5$ Hz. Finally the site category 4 relates to soft soil sites; thick soft alluviums with $V_s < 300$ m/s over 1st 30m depth and $\text{SAM} < 2$ Hz. This preliminary ranking is based both on the studies on 50 sites where geotechnical measurements were performed (compressional and shear wave velocity and microtremor measurements) and three component accelerograms were used to calculate the receiver function for the strong motions. The result of this classification is presented in table-I (Zaré et al 1999a):

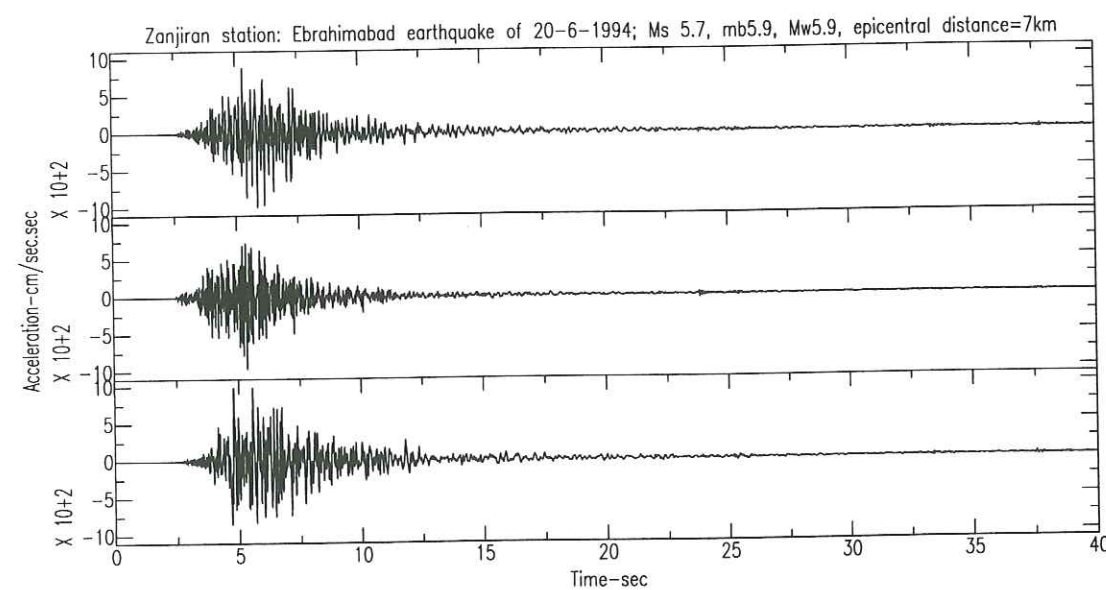


FIG. 2.12 – Three component acceleration time history of the Ebrahimabad earthquake of 20-6-1994 recorded at Zanjiran before filtering. The middle record is the vertical and the two others are the horizontal components.

Table-I: The 4 class site categorization

Group	Frequency Band of the Amplification	V_{s30} m/s	Sites
1	$F \geq 15\text{Hz}$	$V_{s30} \geq 700$	Abbar, Deyhuk, Ghaen, Jovakan, Kakhk, Naghan, Saadabad, Tabas
2	$5 \leq F < 15\text{Hz}$	$500 \leq V_{s30} < 700$	Kavar, Maku, Manjil, Vendik, Zanjiran
3	$2 \leq F < 5\text{Hz}$	$300 \leq V_{s30} < 500$	Fin, Firouzabad, Ghazvin, Golbaf, Rudbar, Zarrat
4	$F < 2\text{Hz}$	$V_{s30} < 300$	Abhar, Lahijan, Hosseinieh, Rudsar, Shabankareh, Tonkabon, Talesh

Among the methods that we have used to study the site conditions, the only method that may reveal the site response to ground motions is to study the three component strong motion records. The benefit gained from this method is that we had at least one record in each of the stations and this is the only method which may be applied at each location. The velocity profiles that we measure by the geoseismic methods are limited to the first 30-35 metres; the microtremors have shown important amplifications just in the soft soil sites, and the geoelectric

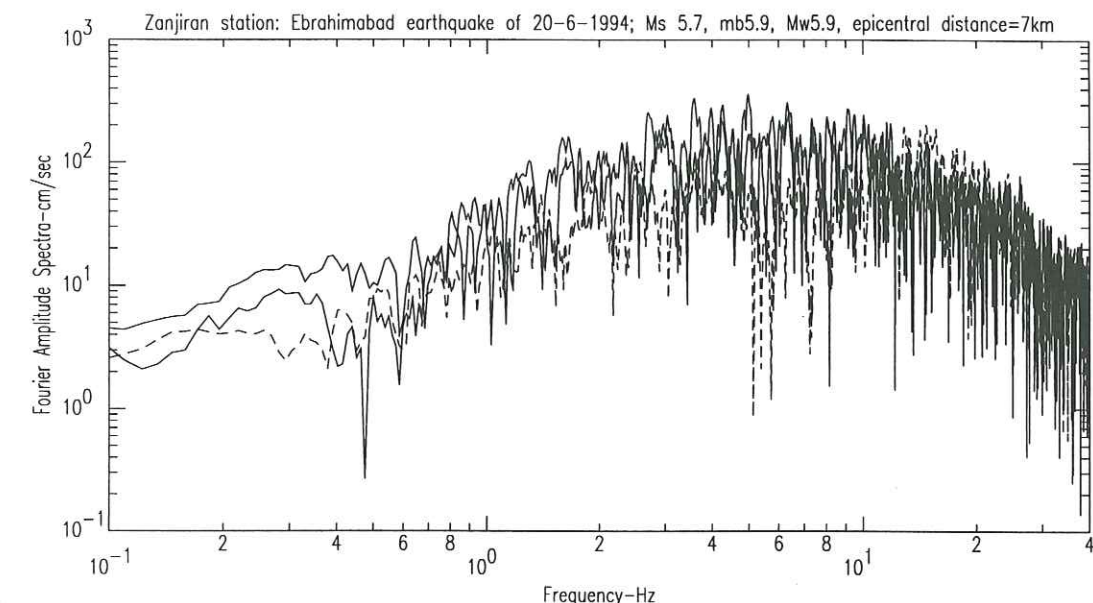


FIG. 2.13 – Fourier amplitude spectra of the Zanjiran record before filtering. The dotted line is the spectrum for the vertical component.

tests do not give the precise measurements to distinguish the different sites. Meanwhile, if there are thick alluvial layers on the surface (with a thickness of more than 30 metres) on a very high velocity layer at greater depths, the H/V spectrum for the strong motion (the receiver function) is the only way to observe such an amplification in low frequencies. In this case the other methods will show just the high velocity alluvium with some amplifications in high to very high frequencies (more than 15Hz).

2.6 Assigning a Quality Label to each Record

A four class categorization is used to grade the quality of each record; « A » corresponds to the best quality and « D » to the worst. Four criteria are taken into account for this categorization; 1. The quality of digitalization of the analog records (corresponding generally to low PGA records). 2. The source focal depth (should be unequal to 33 km). 3. The macroseismic epicentral distance. 4. The source mechanism. If these conditions are available for one record, then its label is assigned « A », and in the absence of each of these cases the quality factor

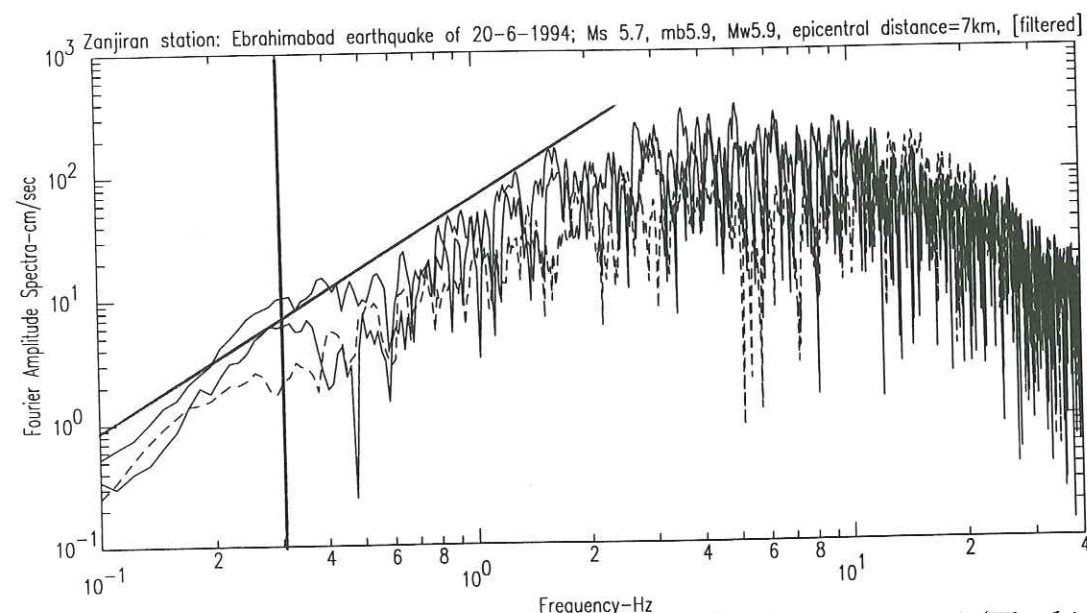


FIG. 2.14 – The filtered Fourier amplitude spectra of the Zanjiran record (The high-pass filter of 0.3Hz is used). The dotted line is the spectrum for the vertical component.

diminishes to « B », « C »,... but the worst records which are chosen had at least the earthquake « magnitude » and the epicentral distance (instrumental) which are referred to as « D ».

2.7 Sources of Errors and Uncertainties

Some expected sources of uncertainties during this study may originate from:

2.7.1 Instrumental and macroseismic epicentral distances

As most of the source parameters are based on the teleseismic data, an uncertainty may originate from the lack of precision in the epicenters location, and the consequences on the estimates of epicentral distances. According to ISC monthly bulletin, the accuracy of the localization in the last 20 years has been different from about 0.01 (approximately about 1 km in a geographical coordinate such as Iran) for the great earthquakes with magnitudes more than $M7.0$, to about 0.15 (approximately about 15 km for such a region) for the earthquakes with magnitudes about $M4.0$. We have however the feeling that these precision estimates are very

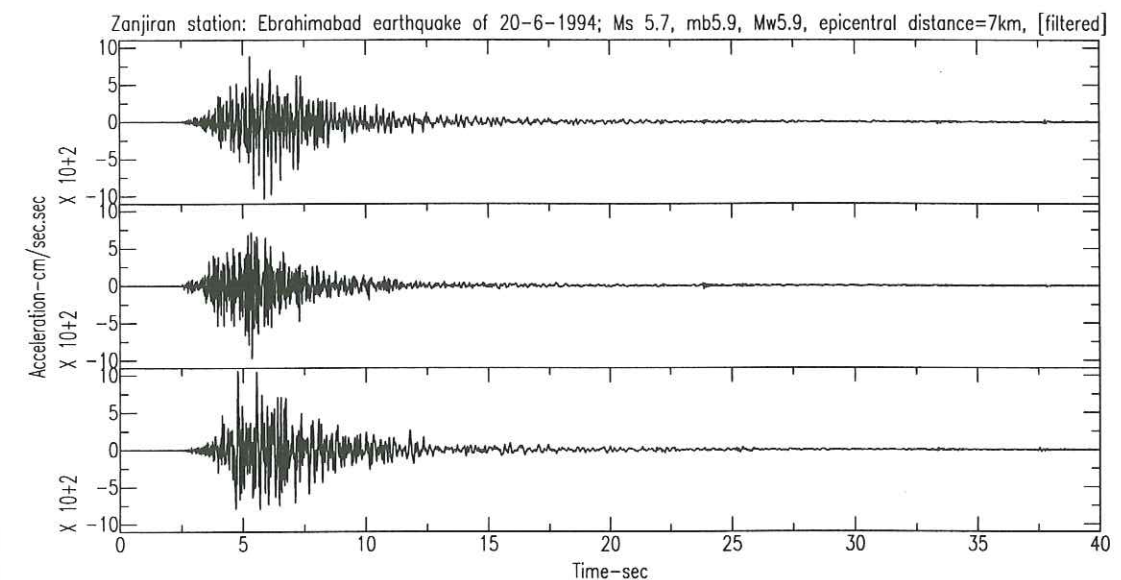


FIG. 2.15 – The filtered three component acceleration time history of the Zanjiran record (The high-pass filter of 0.3Hz is used). The middle record is the vertical and the two others are the horizontal components.

optimistic and should be at least doubled.

The macroseismic epicenters are based on damage reports, whenever available (which is possible only in the inhabited areas), as well as the surface earthquake fault ruptures if there was evidence. Therefore the distances to macroseismic epicenters depend greatly on the presence (or absence) of damage reports, the geographic distribution of the inhabited regions and finally on the presence of the surface rupture. Each of these factors (especially this fact that in most of the cases, the causative fault had no new surface ruptures) may result in the distances to the macroseismic epicenter being uncertain. From this point of view, the great earthquakes are the exceptions (Vendik 1976, Naghan 1977, Ghaen 1978, Tabas 1978, Ghaen 1979, Korizan 1979, Koli-Bonyabad 1979, Golbaf 1981, Sirch 1981, Manjil 1990 and Ebrahimabad 1994), such that the damage reports on these cases are more precise and the causative faults are well known.

For part of the records (mainly SSA-2 which have a pre-event memory) it was possible to estimate the hypocentral distance using the well-known formula: $D_{hypo} = 8 * (ts - tp)$ Where tp and ts are the first arrivals of the P and S waves, respectively. This formula was compared

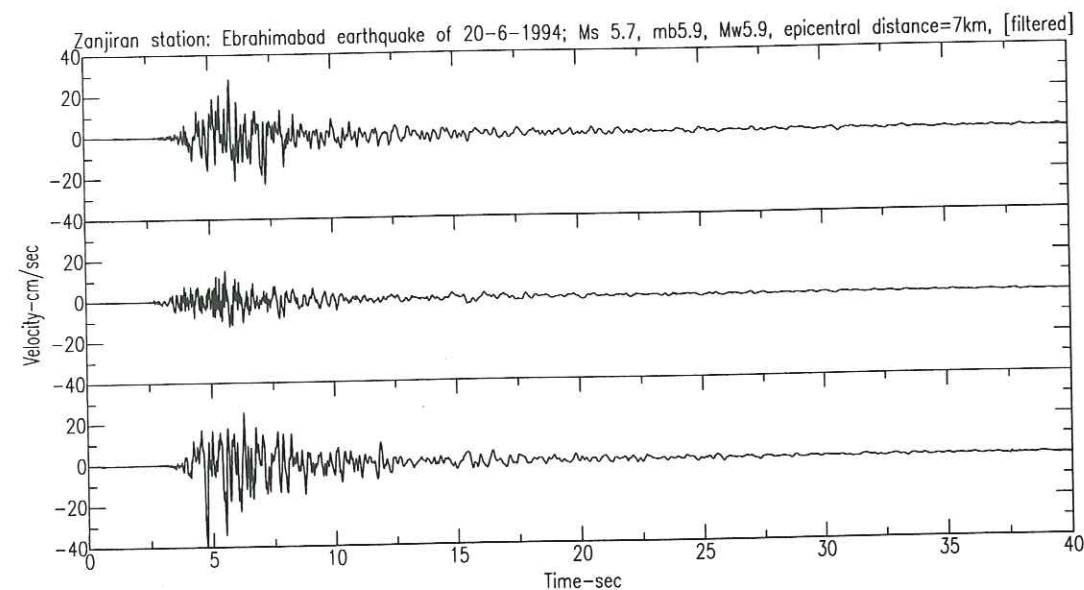


FIG. 2.16 – Three component velocity time history of the Zanjiran record after the integration of the acceleration. The middle record is the vertical and the two others are the horizontal components.

with the epicentral distances and focal depths as inferred for ISC and/or NEIC locations. This distance was not computed for the near-field records of large event, because it was not possible in many cases to identify clearly the P and S waves. As may be seen in Appendix 1, these values are not always consistent with one another. This is another hint that epicenter location in Iran is not very precise.

2.7.2 Focal depths

The earthquakes in the Iranian plateau are mostly of the crustal type origin and, as was shown before, most of those considered in this study were superficial (depths less than 35 km). According to the ISC monthly bulletins, the precision of focal depths is different by as much as ± 4 km for the well determined superficial earthquake (generally the events with the magnitudes more than M6) to ± 30 km for the poorly determined events (generally the small earthquakes with the magnitudes less than about M4). Therefore, it may be concluded that precision of the focal depths is even less than the precision involved in the location of the

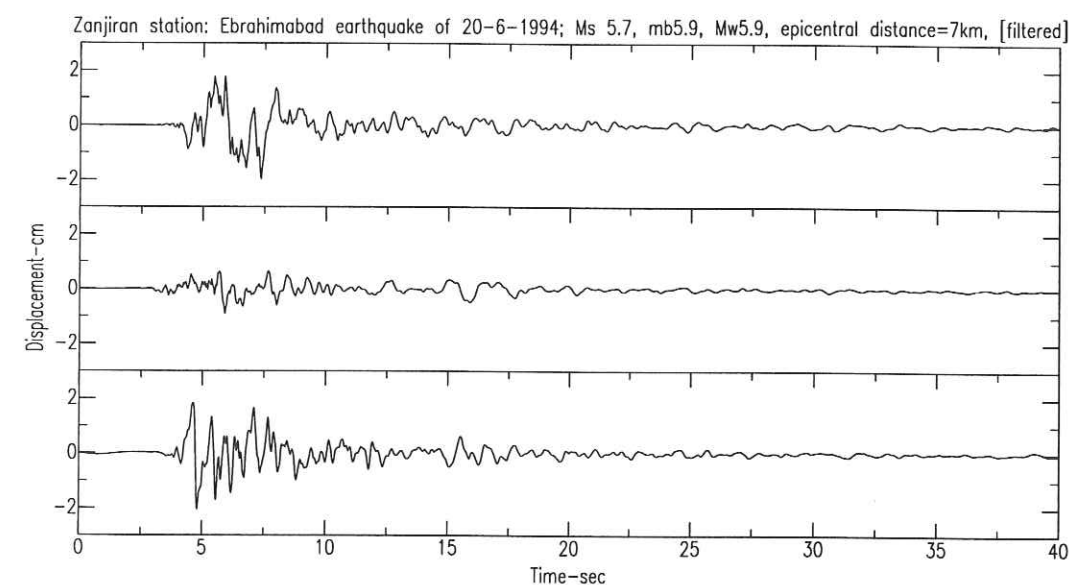


FIG. 2.17 – Three component displacement time history of the Zanjiran record after the integration of the velocity. The middle record is the vertical and the two others are the horizontal components.

epicenter.

2.7.3 Integration of the filtered records

The integration to obtain the velocity and displacement time-histories may cause some uncertainties especially for the analog recordings, since the presence of even little high frequency or low frequency noises may cause some differences in the peak values. The high-pass filtering that we applied was intended to eliminate this low frequency noise. This low frequency cut off certainly cuts some signal so that the peak velocity and peak displacement values may be biased (underestimated) in some cases.

2.7.4 Earthquake intensities

It has been explained (to determine the macroseismic epicenters) that earthquake intensities are strictly based on observations and reports. According to the qualitative nature of

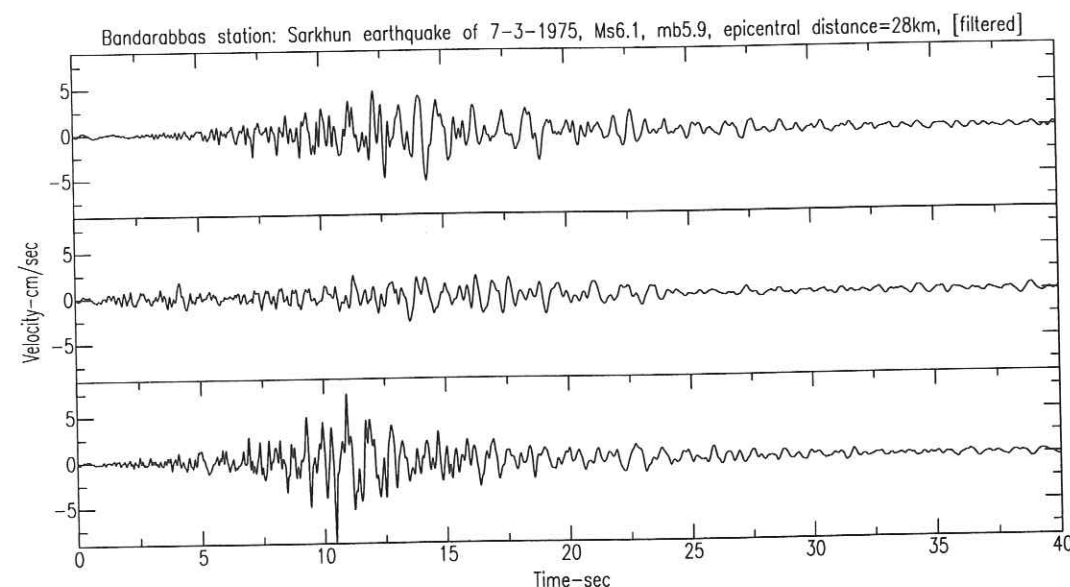


FIG. 2.18 – Three component velocity time history of the Bandarabbas record after the integration of the acceleration. The middle record is the vertical and the two others are the horizontal components.

intensity measurements, different intensities may be presented for one single earthquake by different investigators. On the other hand, in order to compare the different damaged areas with earthquakes with same magnitudes and epicentral distances, we have endeavored to present all the intensities on a single scale (MSK). In this regard, the previously reported intensities on other scales are converted to this scale using the comparison chart of Japan TC-4 (1992). The nature of the intensity measurements and the quality of the reports from the damages or shocked zones, as well as the conversion of the intensities to MSK scale, may be the origin of many uncertainties.

2.8 Conclusion

The first Iranian strong motion catalog (Appendix 1) was developed in this study. This catalog comprises the source and site information for each selected three-component record as well as the maximum values of the acceleration, velocity and displacements. The data-set

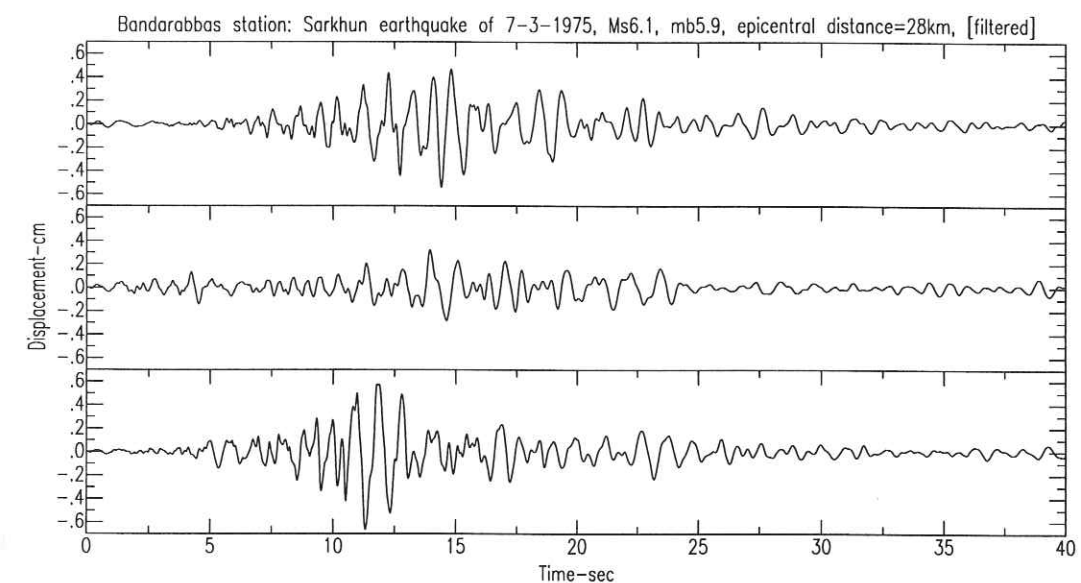


FIG. 2.19 – Three component displacement time history of the Bandarabbas record after the integration of the velocity. The middle record is the vertical and the two others are the horizontal components.

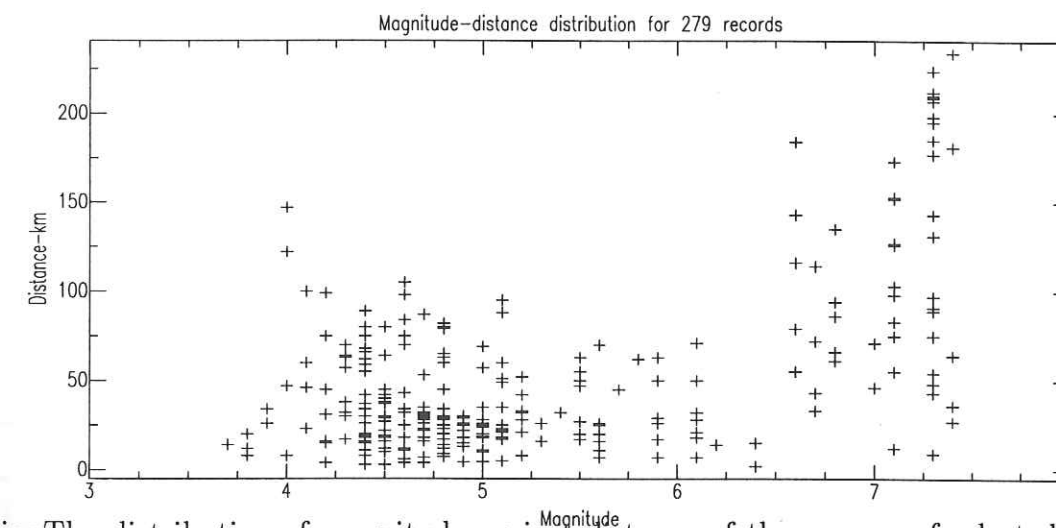
contains the intensity and focal mechanism of the causative events (whenever available). This catalog provides a set of 279 three-component records, with a satisfactory quality and for which we could find their source parameters. There are 169 SMA-1 (analog) and 108 SSA-2 (digital) record in this set. According to the selected sources in this catalog, the geographical distribution of the epicenters indicates that the Zagros region was the most seismically active during the last twenty five years in the Iranian plateau. The most important earthquakes in this catalog are; Sarkhun (Bandarabbas) earthquake of 7-3-1975 (Ms6.1, mb5.9; 3 records for the mainshock and 2 for the aftershock); Vendik (Ghaen) earthquake of 7-11-1976 (Ms6.4, mb5.8; 4 records); Khurgu earthquake of 21-3-1977 (Ms7.0, mb6.2; 2 records); Naghan earthquake of 6-4-1977 (Ms6.1, mb5.6; 4 records for the mainshock and 3 for the aftershock); Tabas earthquake of 16-9-1978 (Ms7.3, mb6.7, Mw7.4; 5 records for the mainshock and 6 for the aftershocks); Ghaen earthquake of 16-1-1979 (Ms6.8, mb6.0; 5 records), Korizan (Ghaen) earthquake of 14-11-1979 (Ms6.6, mb6.0; 6 records) Koli-Bonyabad (Ghaen) 27-11-1979 (Ms7.1, mb6.1; 12 records), Golbaf (Kerman) earthquake of 11-6-1981 (Ms6.7, mb6.1; 3 records), Sirch (Kerman)

earthquake of 28-7-1981 ($M_s 7.1$, $m_b 5.7$, 2 records for the mainshock and 6 for the aftershocks), Manjil earthquake of 20-6-1990 ($M_s 7.7$, $m_b 6.8$, $M_w 7.3$; 18 records for the mainshocks and 20 for the aftershocks); Ebrahimabad (Firouzabad) earthquake of 20-6-1994 ($M_s 5.7$, $m_b 5.9$, $M_w 5.9$; 5 records for the mainshock and 6 for the aftershocks).

It must be noticed that there are other good quality recorded three component accelerograms in BHRC collection but they could not be selected in Appendix 1 because they could not be assigned to any particular earthquake [due to the lack of timing on SMA-1 instruments].

The Iranian strong motion data (Appendix 1) are recorded mostly in the Zagros mountains, western Alborz and northern Lut areas. The distribution of the records is shown in (Figure 2.8 in a diagram of the magnitudes against the distances. This figure shows that most of the records are obtained in the magnitude range of $M 4-5$ and in the distance range of zero to 100 kilometers. The great earthquakes are recorded, as well, in this network (in the range of $6.5 < M < 8.0$ within a distance range of 5 to 230 km). Therefore, it seems that the attenuation relationships that will be developed on these data will be most reliable in the mentioned ranges of magnitudes and distances. The digital data which will be obtained in the future may fill the gaps between the mentioned ranges. On the other hand, it is still necessary to obtain more data in the near field especially in the range of great events ($M 6-8$), in order to develop reliable analyses in the near field and to perform detailed studies on the source and/or site effects. Until that time, it seems difficult to perform detailed near field studies with the present (especially in the magnitude range of $M 6-8$).

In the capital, Tehran, the strong motion records are mostly limited to the Manjil earthquake corresponding to a distance of about 200 km. No important records were obtained (with high acceleration values) in the regions of country similar to the situation of the Tehran plain. Meanwhile there is concern that a great event may shock the capital in an unpredictable time in the future. Therefore, we suggest strongly the installation of dense accelerometric arrays in Tehran and other major and most hazardous cities of Iran such as Ghazvin, Tabriz, Mashhad, Shiraz, Shahr-e Kord, Naein, Zahedan, Tabas, Kashmar, Gorgan, Kazerun, Birjand, Ardebil and Kerman which have situations comparable to Tehran considering site conditions and distances to the earthquake sources. This would be important to obtain meaningful data-sets for reliable microzonation and hazard studies in Tehran and in the mentioned cities. In general, the Iranian network may provide strong motion data not only for herself, but also to share these data with the other neighboring countries with similar seismic source conditions such as Turkey, Iraq, Afghanistan and Pakistan, as well as with the central Asian and Caucasus republics.



caption The distribution of magnitude against distance of the sources of selected records for the present study.

Acknowledgements

Many individuals have assisted us in this paper; most notably Mr. Mehdi Heydari (in IIEES) assisted this project to provide the source data. The BHRC (Building and Housing Research Center, Tehran) who have released the raw strong motion records is greatly acknowledged. The financial support in Iran was provided by IIEES, and in France (for the first author) was provided by a French scholarship (Ministère Français des Affaires Etrangères), which are both duly acknowledged. We thank Mr. Mohammad Zaré (the father of first author) who has provided the reports of the Persian dailies on the earthquake damages in Iran during the period of 1974-1996. Our thanks also go to Douglas McLean who has proof-read this text and has given comments to correct the orthography.

Appendix 1 The catalog of the accelerometric data of Iran (the published data since the beginning of its installation until the end of February 1996). The references are;

- 1: NEIC (PDE monthlies of the National Earthquake Information Center, USGS),
- 2: ISC (monthly bulletin of the International Seismological Center, UK),
- 3: Ambraseys and Melville, 1982 (Ref. No.2),
- 4: Newspapers (the Persian language newspapers published in Iran since 1974 until the end of February 1996),
- 5: IGTU (the catalog of the Institute of Geophysics Tehran University),
- 6: Zaré (1994),
- 7: Eshghi et al (1994).

No	Code (BHR)	Station	Site	Files to process (1st filtering for acceleration & velocity)			Files to process (2nd filtering for Displacement & velocity)			Peak Ground Acceleration (cm/s ²)			Peak Ground Velocity (cm/s)			Peak Ground Displacement (cm)			Macroseismic epicenter (Region)	Date	Ms	mb	ML	Focal Depth (km)	Epicentral Distance (km)	Hypocentral Distance (km)	Macroseismic epicenter distance (km)	Intensity (MSK)	Focal Mechanism	Ref
				HP	LP	LP	HP	LP	H1	V	H2	H1	V	H2	H1	V	H2													
1	1012	Kuamir	2	2.5	15	41	14.5	30											11/5/74		4.5			64					C 1	
2	1005-1	Bandarabbas (S)	2	0.0	20	79	38.5	184	7.2	4.0	8.2							3/7/75	Sarhan (Al Shad)	6.1	5.9			27	28	48		Rv	A 1,3,4	
3	1005-2	Bandarabbas (S)	2	1.5	6	17	13	27										3/7/75	Sarhan (Al Shad)	6.1	5.9			27	28	40		Rv	D 1,3	
4	1007	Mhrab	1	2.5	9	18.5	11.5	17.3										3/7/75	Sarhan	6.1	5.8			27	30	60		Rv	B 1,3	
5	1008	Ghashm Island	1	2	7	15	14.2	14.2										3/7/75	Sarhan	6.1	5.8			27	30	60		Rv	B 1,3	
6	1013	Tonkolan	4	1	8	49	9.7	25										3/7/75	Sarhan (Al Shad)	4.1	4.4			34				D 2		
7	1009	Mhrab	1	1.5	5	34	7.8	17.3										4/13/75	Sarhan (Al Shad)	4.1	4.4			34				D 2		
8	1026	Shraz	4	1.5	33	64	46	44										6/2/75	Hahab	4.1	4.1			52	56	48		D 2		
9	1014-4	Hahab	3	1	15	77	52	82										10/9/75	Mahrash-Tappah	5.4	5.3			33a	0			C 1,2		
10	1024	Mahrash-Tappah	3	1-H, 4-V	40	372	185	397	7.5	2.72	10.6							12/21/75	Mahrash-Tappah	3.9	4.8			29				C 2		
11	1024-1	Moku	2	1	20	47	36	81	1.2	0.88	1.5							4/2/78		4.7	5.1			48	98	12		C 2		
12	1024-2	Moku	2	1.5	30	201	78	110										9/5/78	Verdik	4.7	5.1			44	68			B 1		
13	1043	Napghan-1	2	0.05	40													Verdik	11/7/78	8.4	5.8			13	15	10		VH	A 1,2	
14	1047-8	Vandik	2	0.4 BHR	25	115	170	157	9.8	6.4	14.8							Verdik	11/7/78	8.4	5.8			13	2			SS	A 1,2,3,4	
15	1047-9	Vandik	2	1.5	40	180	105	120	3.1	2.8	6.9							Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
16	1047-10	Vandik	2	0.4	40	40	1.3	40	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
17	1041-10	Vandik	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
18	1048-1	Moku	2	0.4	40	40	1.3	40	205	87	182	1.8	0.55	2.3				Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
19	1048-2	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
20	1048-3	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
21	1048-4	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
22	1048-5	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
23	1048-6	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
24	1048-7	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
25	1048-8	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
26	1048-9	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
27	1048-10	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
28	1048-11	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
29	1048-12	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
30	1048-13	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
31	1048-14	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
32	1048-15	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
33	1048-16	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
34	1048-17	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
35	1048-18	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
36	1048-19	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
37	1048-20	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
38	1048-21	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
39	1048-22	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
40	1048-23	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
41	1048-24	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
42	1048-25	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
43	1048-26	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
44	1048-27	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
45	1048-28	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
46	1048-29	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
47	1048-30	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
48	1048-31	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
49	1048-32	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
50	1048-33	Moku	2	3	15	40	205	87	182	1.8	0.55	2.3						Verdik	11/7/78	4.8	4.8			1	8	4		SS	A 1,2	
51	1048-34	Moku	2	3	15	40	205	87	1820																					

[illegible]

No	Code (B-HC)	Station	Site	Filters to process (1st filtering for acceleration & velocity)				Peak Ground Acceleration (cm/s ²)				Peak Ground Velocity (cm/s)				Peak Ground Displacement (cm)				Macro seismic epicenter (Region)	Date	M _s	m _b	M _L	W ₀	Focal Depth (km)	Epicentral Distance (km)	Hypocentral distance (km)	Macro seismic epicenter distance (km)	Intensity (MSK)	Focal Mechanism	Q	Ref
				HP	LP	HP	LP	H1	V	H2	V	H1	V	H2	V	H1	V	H2	V														
226	1578	Kunesak	3	0.2	0.7	7.3	3.7	0.1	0.265	0.060	0.32	0.01	0.0267	0.013	14/05	4.6	4.6	3.3	105												C 1		
227	1532	Deh-Bala - N. Farash	2	0.1	0.8	35	18	31	0.55	0.52	0.48	0.025	0.017	0.024	12/10/05	5.1	4.7	4.8	3.3	32											C 1.5		
228	1528-3	Fin	3	0.1	0.8	545	418	498	16	9.5	14.5	0.67	0.35	0.81	2/19/05	4.4	4.3	3.3	55												B 1.4		
229	1555	Farashabad	3	0.1	0.8	16	9.2	14	0.41	0.16	0.42	0.017	0.0054	0.018	2/19/05	4.4	4.3	3.3	55												B 1.4, 5		
230	1547-1	Safid Dam (Crest)	1	0.2	0.8	59	16	12	1.9	0.27	0.53	0.075	0.012	0.031	3/06/05	4.3	4.3	3.3	70												C 1		
231	1563	Dorshun	3	0.2	0.8	230	1547-1	Safid Dam (Crest)	1	0.2	0.8	18	13	15	0.44	0.165	0.44	0.028	0.0058	0.023	3/06/05	4.3	4.3	3.3	23							C 1.4, 5	
232	1564	Baba-Mone	4	0.2	0.8	230	1547-1	Safid Dam (Crest)	1	0.2	0.8	18	13	15	0.44	0.165	0.44	0.028	0.0058	0.023	3/06/05	4.3	4.3	3.3	23							C 1	
233	1575-1	Kashan	4	0.1	0.8	24	12	20	0.63	0.34	0.89	0.038	0.0065	0.025	4/22/05	4.5	4.5	3.3	40												B 1.4		
234	1585-1	Shahr-e Kord	2	0.1	0.8	21	14	20	0.8	0.165	0.45	0.029	0.011	0.021	4/22/05	4.5	4.5	3.3	30												B 1.4, 5		
235	1585-1	Shahr-e Kord	2	0.1	0.8	21	14	20	0.8	0.165	0.45	0.029	0.011	0.021	4/22/05	4.5	4.5	3.3	30												B 1.4		
236	1585-1	Shahr-e Kord	2	0.1	0.8	21	14	20	0.8	0.165	0.45	0.029	0.011	0.021	4/22/05	4.5	4.5	3.3	30												B 1.4		
237	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
238	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
239	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
240	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
241	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
242	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
243	1581	Band-e Deylam	4	0.1	0.8	17	11	14	0.5	0.11	1.15	0.105	0.016	0.135	4/22/05	4.8	5.1	25	95												A 1		
244	1584	Konamin	2	0.1	0.4	24	21	22	0.35	0.12	0.44	0.017	0.008	0.02	5/17/05	4.0	3.9	3.9	47												B 1		
245	1543	Konamin	2	0.1	0.4	24	21	22	0.35	0.12	0.44	0.017	0.008	0.02	5/17/05	4.0	3.9	3.9	47												B 1		
246	1590-2	Sasak	1	0.3	1.8	20	6	15	0.35	0.125	0.435	0.013	0.0058	0.017	5/17/05	3.8	4.8	3.9	102												C 1.4, 5		
247	161833-1	Narm	3	0.1	0.8	21	11	15	0.53	0.53	0.72	0.02	0.014	0.051	5/17/05	4.0	4.0	3.9	20												B 1		
248	151533-2	Saifabad (S. Kuzum)	3	0.1	0.8	21	11	15	0.53	0.53	0.72	0.02	0.014	0.051	5/17/05	4.0	4.0	3.9	20												B 1		
249	1620-1	Darb (Pole Sift)	3	0.1	0.8	21	11	15	0.53	0.53	0.72	0.02	0.014	0.051	5/17/05	4.0	4.0	3.9	20												C 1.4		
250	1628	Hassan-Kel	3	0.2	0.8	59	37	35	1.89	0.72	1.0	0.052	0.018	0.051	16/05/05	4.2	4.1	3.9	5												C 1.4		
251	1630-1	Hassan-Kel	3	0.2	0.8	59	37	35	1.89	0.72	1.0	0.052	0.018	0.051	16/05/05	4.2	4.1	3.9	5												C 1.4		
252	1647-1	Darb (SE Sift)	2	0.1	0.5	45	3	7	0.30	0.143	0.19	0.025	0.005	0.025	16/05/05	3.9	4.4	3.9	20												C 1		
253	1537	Safid Dam	1	0.2	0.2	20	12	10	0.85	0.37	0.77	0.12	0.055	0.047	16/05/05	4.3	4.7	3.9	14												C 1		
254	1541	Rast (University)	3	0.1	0.1	16	8	4	0.5	0.34	0.70	0.074	0.035	0.29	10/15/05	4.9	5.2	3.9	32												SSPa		
255	1615-1	Abbar	1	0.1	0.1	11	8	8	0.89	0.33	0.69	0.021	0.012	0.019	10/15/05	4.9	5.2	3.9	28												SSPa		
256	1632-1	Mesal	3	0.1	0.5	20	17	28	0.52	0.47	1.0	0.043	0.035	0.060	10/15/05	4.9	5.2	3.9	28												B 1		
257	1588	Zarfall - N. Bardarab	1	0.1	0.4	20	17	28	0.52	0.47	1.0	0.043	0.035	0.060	10/15/05	4.9	5.2	3.9	28												B 1		
258	1635-2	Shahr-Gil (Kahnu)	1	0.1	0.4	20	17	28	0.52	0.47	1.0	0.043	0.035	0.060	10/15/05	4.9	5.2	3.9	28												B 1		
259	1539	Mashed (Shahr)	1	0.1	0.5	41	19	40	0.59	0.29	0.465	0.038	0.015	0.040	10/15/05	4.9	5.2	3.9	28												B 1		
260	1589	Marmud	1	0.1	0.7	118	159	88	3.8	2.45	2.7	0.101	0.035	0.023	11/24/05	4.5	4.1	3.9	15												C 1.4		
261	1590-1	Lail (Shahr)	3	0.1	0.5	14	7.1	18	0.4	0.17	0.98	0.04	0.014	0.125	11/24/05	4.5	4.1	3.9	15												C 1.4		
262	1590-4	Mashed-Sakman	3	0.1	0.5	80	61	107	2.6	1.97	3.40	0.02	0.0125	0.022	11/24/05	4.5	4.1	3.9	15												C 1.4, 5		
263	1590-4	Mashed-Sakman	3	0.1	0.5	80	61	107	2.6	1.97	3.40	0.02	0.0125	0.022	11/24/05	4.5	4.1	3.9	15												C 1.4, 5		
264	1590	Shraz	4	0.2	0.4	12	8	10	0.87	0.158	0.53	0.04	0.035	0.047	11/24/05	4.5	4.1	3.9	15												B 1		
265	1602-1	Kevir Dam	2	0.3	0.4	28	13	32	1.2	0.38	0.89	0.072	0.023	0.052	11/24/05	4.2	4.3	3.9	30												B 1		
266	1602-2	Kevir Dam	2	0.3	0.4	28	13	32	1.2	0.38	0.89	0.072	0.023	0.052	11/24/05	4.2	4.3	3.9	30												B 1		
267	1571-6	Shabankarsh (Boraz)	4	0.5	1.3	130.8	37.5	65.8	3.37	0.999	1.82	0.115	0.0123	0.052	11/24/05	4.2	4.3	3.9	30												B 1		
268	1571-11	Shabankarsh (Boraz)	4	1.2	10.3	8.90	12.20	30.3	1.2	0.387	0.999	0.009	0.0024	0.0122	11/24/05	4.2	4.3	3.9	30												B 1.4, 5		
269	1571-18	Shabankarsh (Boraz)	4	0.6	19.3	10.8	21.5	4.4	0.19	0.63	0.975	0.009	0.0024	0.0122	11/24/05	4.2	4.3	3.9	30												C 1.4, 5		
270	1583-3	Safidabad (Boraz)	1	0.6	74	22.2	45.9	2.2	0.51	0.95	0.975	0.009	0.0024	0.0122	11/24/05	4.2	4.3	3.9	30												C 1.4, 5		
271	1571-30	Safidabad (Boraz)	1	0.4	34.1	8.98	18.3	0.97	0.205	0.565	0.975	0.009	0.0024	0.0122	11/24/05	4.2	4.3	3.9	30												B 1		
272	1571-30	Safidabad (Boraz)	1	0.8	21.9	14.9	24.4	0.44	0.17	0.50	0.975	0.009	0.0024	0.0122	11/24/05	4.2	4.3	3.9	30												B 1		
273	1583-7	Safidabad (Boraz)	1	0.4	26.2	8.98	18.3	0.97	0.205	0.565	0.975	0.009	0.0024	0.0122	11/24/05	4.2	4.3	3.9	30												B 1.5		
274	1571-32	Shabankarsh (Boraz)	1	0.4	274	1571-32	Shabankarsh (Boraz)	1	0.4	274	1571-32	Shabankarsh (Boraz)	1	0.4	274	1571-32	Shabankarsh (Boraz)	1	0.4	274	1571-32	Shabankarsh (Boraz)	1	0.4	274	1571-32	Shabankarsh (Boraz)	1	0.4	274	1571-32	C 1	
275	1571-34	Shabankarsh	4	0.1	0.8	28.7	17.3	38.0	0.82	0.32	0.68	0.009	0.003	0.005	11/24/05	4.3	4.3	3.9	11												C 1		
276	1571-35	Shabankarsh	4	0.1	0.8	28.7	17.3	38.0	0.82	0.32	0.68	0.009	0.003	0.005	11/24/05	4.3	4.3	3.9	11												C 1		
277	1589-1	Safidabad (Boraz)	1	0.3	15.6	5.23	16.1	0.56	0.125	0.44	0.63	0.003	0.003	0.017																			

Appendix 2 Some Examples of determining the macroseismic epicenters

Some of the epicenters are relocated, based on the damage reports and the reports by the national Iranian seismic network. The following explained events are those their macroseismic epicenter (based on the damages to the inhabitant areas) were not already reported. The suggested intensities in Appendix 1 may be compared with the accelerations registered in the same place, and may provide a bases for possible studies on the attenuations of the intensities in Iran. The suggested intensities - all in MSK scale - are presented in Appendix 1. All of the following mentioned localities are shown in Figure 2.6. The most important cases are explained briefly here in:

- Vendik earthquake 7-11-1976 (Ms6.4; mb5.8) demolished Vendik village in the north of Ghaen. A visit to Vendik (December 1996) made it clear that the village was evacuated after the quake. Almost all of the buildings were destroyed. Another village (Kalateh-e Hadj-Mohammad-Alam) in a distance of about 7 km towards north east of Vendik, has also been destroyed but as the inhabitants (who still work in the farmlands of Vendik) said, the damages in Hadj-Mohammad-Alam were less severe than in Vendik. Twelve people have died in Vendik. This quake made some losses in Ghaen (12 people injured with some buildings destroyed).

- Chalderan earthquake 24-11-1976 (Ms7.3; mb6.1; ML6.8) shocked a frontier region between Iran and Turkey. The quake caused a lot of damage in the Iranian side of the frontier. Several landslides (in the form of rock-block slides and debris slides) were reported in areas near Maku, Siah-Cheshmeh and Kelisa-Kandi. One person was reported dead in Siah-Cheshmeh, and in Maku two great blocks fell on some rural buildings of the city and caused a lot of damages. Another quake which may be thought of as the aftershock of the Chalderan earthquake has shaken Siah-Cheshmeh in 6-12-1976 (Ms4.2, mb4.4).

-Chourzagh (Tarom-Olia) earthquake 22-7-1983 (Ms5.0; mb5.6) in the north Zanjan province caused some losses (3 killed and 38 injured in Chourzagh). The property losses were reported from Chourzagh, Abbar and Hendi-Kandi areas.

- Tonkabon earthquake 20-12-1983 (mb4.8; ML4.5), shocked the city of Tonkabon and its suburban villages. The Tehran station of IGTU reported a foreshock of a magnitude ML3.0, and some aftershocks with magnitudes between ML3.0 to ML3.7, but no more data is published on the times and the locations of these foreshock and aftershocks.

- Kaboudar-Ahang earthquake 9-5-1985 (ML3.1) is just reported by the local stations of the national network (IGTU) that shocked the region between Kaboudar-Ahang and Razan.

- Fataviyeh (Bastak) earthquakes 16-1-1987 (ML4.5), and 19-1-1987 (ML4.0) are registered

in the site of the Ol d-Lar city in southern Zagros, and are just reported by the local stations of the IGTU. Some 40 aftershocks followed these two main events. Based on some reported minor quake impressions in the Fataviyeh villages and its suburbs, an intensity of III is estimated for the epicentral area.

- Kohan (Kuhbanan) earthquake 11-4-1987 (Ms4.5; mb5.0) caused panic among the inhabitants and some damage in form of the rural building collapses in the village of Kohan and the breaking of windows in the city of Kohbanan.

- Gol (Khusf) earthquake 24-11-1987 (mb5.3) caused some damage in the Gol villages and Khusf city in the west and southwest of Birjand.

- Rostamabad earthquake 28-11-1991 (Ms5.0; mb5.6; ML5.5) damaged some recently reconstructed buildings (after the great earthquake of Manjil 20-6-1990, Mw7.3 in the same region). Two people collapsed and died in the panic provoked by this shock.

- Ebrahimabad (Firouzabad) earthquake 20-6-1994 (Ms5.7; mb5.9; Mw5.9) caused severe damages in the central Zagros area between Shiraz and Firouzabad. The quake demolished the most of the buildings in Ebrahimabad, Jovakan and Zanjiran. Some minor damage was observed in Firouzabad (some cracks in walls and minor damages in the rural buildings). Three people were killed in this earthquake (2 in Ebrahimabad and one in Zanjiran).

Chapitre 3

Les Effets de Site

Résumé Les effets de site sont étudiés dans ce chapitre en utilisant les données de mouvements forts enregistrés par le réseau accélérométrique iranien. Vingt-six sites ont été choisis pour des mesures géosismiques. Le bruit de fond y a été enregistré, ainsi que dans vingt-quatre autres sites où ces mesures ont été les seuls tests réalisés. Des tests géoélectriques ont également été effectués sur les 24 sites où des études géosismiques ont été réalisées, mais ces résultats n'ont pas été utilisés car leur interprétation ne donnait pas de résultats très intéressants. Les rapports spectraux entre les composantes horizontales et verticales (« fonctions-récepteur ») ont aussi été calculés pour tous les enregistrements du catalogue de mouvements forts iraniens (137 sites en tout). Ces rapports ont été la base de notre classification de site, du point de vue de leurs réponses aux mouvements forts, car ils sont les seuls critères qui existent pour tous les sites, et les seuls qui montrent directement les réponses des sites aux mouvements forts. Ce critère de classification résulte d'une comparaison entre les fonctions récepteurs et les résultats des tests géotechniques (géosismique, bruit de fond). En bref, les sites avec les rapports H/V inférieurs à 3 pour toute fréquence inférieure à 15 Hz ont été considérés comme du 'rocher' (classe 1); les sites avec un rapport H/V dépassant 3 dans la bande de fréquence de 5 à 15Hz ont été classés dans la catégorie 2, ceux avec un rapport H/V dépassant de 3 dans la bande de 2 à 5 Hz sont classés en catégorie 3, ceux montrant un rapport H/V dépassant 3 pour les fréquences inférieures à 2Hz ont été classés dans la catégorie 4. Il s'avère que cette classification se corrèle assez bien (dans 70% des cas) avec la valeur moyenne de la vitesse d'onde S sur les 30 premiers mètres, V_{s30} : pour la classe 1, $V_{s30} > 700$ m/sec; pour la classe 2, $500 < V_{s30} < 700$ m/sec; pour la classe 3, $300 < V_{s30} < 500$ m/sec; et pour la classe 4, $V_{s30} < 300$ m/sec. Le bruit de fond ne présente qu'un accord très partiel avec ces classifications: dans les sites de type de classe 3 et 4 on trouve les rapports H/V présentant une certaine similarité avec les fonctions-récepteurs. Ce résultat mitigé pourrait être la conséquence des situations topographiques (l'existence de deux chaînes des montagnes importantes dans le plateau iranien) et météorologiques (aride et sec) du pays. La classification présentée dans ce chapitre est le premier travail sur les effets de site accompli à partir du réseau accélérométrique en Iran.

Site Characterizations for the Iranian Strong Motion Network

Mehdi Zaré, Pierre-Yves Bard and Mohsen Ghafory-Ashtiany

Article publié dans le "Journal of Soil Dynamics and Earthquake Engineering", 1999, Vol.18, no.2, pp.101-123.

Abstract 26 sites of the Iranian strong motion network, having provided numerous records of good quality, were selected for a site effect study with the objective of obtaining a reliable site categorization for a later statistical work on Iranian strong motion data. For each site, superficial V_p and V_s profiles were measured with refraction techniques, microtremor recordings were obtained and analyzed with the H/V technique and the available three-component accelerograms by the receiver function technique. The aggregation of these results allows the proposition of a four-class categorization based on the H/V spectral ratio of strong ground motions, which demonstrate a satisfactory correlation with S-wave velocity profile. Iran has a particular geological and meteorological situation compared to other seismic countries such as Japan or California; a mountainous country with dry weather condition and low water table in most areas. These conditions result in a relatively small number of sites with low frequency amplification, while many sites exhibit moderate amplifications in the intermediate and high frequency range.

3.1 Introduction

The strong motion accelerometric network in Iran is installed throughout the country in different site conditions. The Kinemetrics SMA-1 analog instruments were initially installed since 1975, and then they have been gradually expanded by the SSA-2 digital instruments since the Manjil earthquake of 1990; $M_w 7.4$, in NW Iran. The number of the instruments in this network is 1000 stations (by the end of 1997). The stations have been mainly chosen within the cities or villages for an easy maintenance. However there are no double stations (functioning as a local network on a soil site and its corresponding rock outcrop) to compare easily the soil and rock motions in different earthquakes. Meanwhile, there is no down-hole array, yet, to compare the motions on the surface and on the base rock.

The previous studies on site effects on the strong ground motions in Iran were limited to some, recent, studies on the soil effects on strong motion records during the great earthquakes (Zaré 1994; 1995; 1996a & 1996b). On the other hand, some microzonation case studies were also performed in some great cities in Iran (Jafari et al 1995, 1996).

The scope of this study was to investigate the site effects on the strong ground motions in Iran. It is also tried to select a variety of different soil and geologic conditions in such a

The results of the site effect studies, and the site classification for strong motion stations in Iran.

No	Station	Site categorization	Number of records	Site geology	Vs over 30 m (m s ⁻¹)	Amplification of H/V on microtremors	Amplification of H/V on strong motions	Site based on surface geology (BHRC)	Electric resistivities (ohmm)	Q
1	Abbar	1	5	Stiff alluvium	621	1	< 4 (2-5 Hz)	3	5-17 (1st 30 m)	A1
2	Abhar	4	1	Silt-clay in surface	263	> 2 (0.2-2 Hz)	> 4 (0.2-0.3 and 1-4 Hz)	4	3-25 (1st 25 m)	A1
3	Aghajari	2	1				> 4 (4-6 Hz)	1		C
4	Ahar	1	1				1-2 (3-10 Hz)	4		D
5	Anmarloo (Jirandeh)	3	6				> 4(3-5 Hz)			C
5	Andimeshk	1	3				2-3 (3-7 Hz)	2		C
7	Ardal	3	4				> 4 (2.5-3.5 Hz)	2		C
8	Ardebil	4	1				> 4(1-2.5 and 4-5 Hz)	3		C
9	Astaneh	4	1				> 4(0.7-2 Hz)	3		C
10	Avaj	1	2				3(4-7 Hz)	4		D
11	Babakan (Gachsaran)	2	1				> 4(7-11 Hz)	2		C
12	Baba-Monir	4	1				> 4(0.9-1.7 Hz)			C
13	Babonar	2	1				> 4(5-6 Hz)	2		D
14	Bajestan	3	3				> 4(3-6 Hz)	4		B
15	Bam	1	1				1-2(0.7-10 Hz)	3		C
16	Bandarabbas (S)	2	3			> 2(2- Hz)	> 4(6-10 Hz)			C
17	Bandar-Deylam	4	1				> 4(0.3-3 Hz)			C
18	Bandar-Lengeh	3	1				> 4(3-5 Hz)	3		C
19	Bandar-Torkman	4	1				> 4(0.9-3.5 Hz)	3		D
20	Birjand	1	4			1(0.2-20 Hz)	1-3(0.7-7 Hz)	2		C
21	Boroujerd	3	1				> 4(2.5-3.5 Hz)	4		C
22	Boshruyeh	1	1				1-2(1-5 Hz)	2		C
23	Bostanabad	4	1				> 4(1-2.5 Hz)	2		D
24	Dalin (SE Sepidan-Fars)	2	1				> 4(5.5-6.5 Hz)			C
25	Dareh-Shahr Ilam	1	1				2-3(2-6 Hz)	2		C
26	Dasgerd	2	1				> 4(8-11 Hz)			C
27	Deh-Balla - N. Farrashband	2	1				> 4(7-11 Hz)			C
28	Delvar	2	1				> 4(9.5-10 Hz)	2	3-5 (1st 12 m)	A2
29	Deyhuk	1	3				2-4(2-15 Hz)	1		C
30	Dez Dam	1	3				1-2(1-15 Hz)	2		C
31	Doab (Pol-e Sefid)	3	5				> 4(2.5-4 and 6.5-8 Hz)			C
32	Dorahun	3	1				> 4(3.5-7 Hz)	3		B
33	Doroud	4	1				> 4(1.5-2.5 Hz)	4	20-80 (1st 25 m)	B
34	Estehard	4	1				4(0.5-0.65 Hz)	1		C
35	Estakhl-Posht	2	1				> 4(5-10 Hz)	3		D
36	Farrashband	1	1				1-3(5-11 Hz)	3		D
37	Farsan	1	1				1-2(5-8 Hz)	2		B
38	Ferdows	1	1				2-3(0.3-5 Hz)	2		A1
39	Fin (N.Bandar-Abbas)	3	31				> 4(2.5-5 Hz)	3	14-90 (1st 33 m)	A1
40	Fiروزabad	3	11				> 4(1.5-4.5 Hz)	2		C
41	Gachsar	3	1				> 4(2.5-4.5 Hz)	2		C
42	Ghaemiyeh (Chenar-Shahjahan)	3	1				> 4(2.5-4.5 Hz)	1		A2
43	Ghaen	1	3				2-3(0.4-0.6 and 3-7 Hz)	2	1.5-100 (1st 21 m)	A2
44	Gavbandi	3	1				> 4(3-6 Hz)			C
45	Ghaleh-Ganj	1	1				2-3(2-11 Hz)	2	10-50 (1st 20 m)	A2
46	Ghazvin	3	1				3-4(1-5 Hz)	2		C
47	Ghesim-Island	1	1				1-2(1.5-8 Hz)	2		C

Table 1 (continued)

No	Station	Site categorization	Number of records	Site geology	Vs over 1st 30 m (m s ⁻¹)	Amplification of H/V on microtremors	Amplification of H/V on strong motions	Site based on surface geology (BHRC)	Electric resistivities (ohmm)	Q
48	Ghir	3	1	Gravel		1(4-15 Hz)	3-4(4.5-5.5 Hz)	1		B
49	Gilvan	1	2				2-3(4-7 Hz)	2		D
50	Golbaf	3	13	Soft alluvium	439	1(4-8 Hz)	> 4(3-5 Hz)	3	4-8 (1st 19 m)	A2
51	Gonabad	4	3	Soft alluvium		1(0.2-40 Hz)	3-4(0.8-1.5 Hz)	3		B
52	Hajiabad	3	1				> 4(3.5-4.5 Hz)	1		C
53	Hassan-Keif	3	1				> 4(2.5-3.5 Hz)			C
54	Hosseiniyeh-Olia	4	11	Soft alluvium	563	1 2(0.2-6 Hz)	> 4(0.3-1 Hz)	1		A2
	Andimeshk									
55	Jovakan	1	30	Soft alluvium in surface	1017	1 2(0.6-9 Hz)	2-3(5-8 Hz)	2	5-30 (1st 25 m)	A1
56	Kahrizak	4	1	Clay and marl		1 2(0.6-2 Hz)	3-4(0.4-2 Hz)	4		B
57	Kakhk	1	1	Sandstone	2200	2 4(0.8-10 Hz)	2-3(1.5-6 Hz)	1		A2
58	Karaj	1	1	Course grain gravels		1(0.4-25 Hz)	1-3(0.5-10 Hz)	2		B
59	Karkheh Dam	1	1				1-3(1-10 Hz)	1		C
60	Kashmar	3	2				3-4(2-3.5 Hz)	2	6-120 (1st 35 m)	A2
61	Kavar	2	13	Hard conglomerate	946	1(1-10 Hz)	2-4(1-9 Hz)	1		C
62	Kavar Dam	2	4				> 4(4-8 Hz)	1		C
63	Kazerun	2	2				> 4(5-11 Hz)	4		C
64	Kerman	4	2	Soft alluvium		3(0.2-1.1 Hz)	> 4(1.5-3 Hz)	3		B
65	Khaf	2	6				> 4(5-8 Hz)	2		C
66	Khanzanun	1	3				2-3(2-7 Hz)	3		C
67	Khezri	1	2	Hard conglomerate		1(0.2-25 Hz)	2-3(0.4-4 Hz)	3		B
68	Khonj	1	1				2-3(3-7 Hz)	3		C
69	Khorramabad	2	3				3-4(4-7 Hz)	2		C
70	Khoy	3	1				> 4(4-4.5 Hz)	2		C
71	Khurmodj	1	1				2-3(3.5-20 Hz)	2		C
72	Kiasar	2	1				> 4(6-7 Hz)	2		C
73	Kolur	1	1	Soft alluvium		1-2(0.3-9 Hz)	> 4(15 Hz)	4		B
74	Kuhbanan	3	1				3-4(2-6 Hz)	2		C
75	Kuestak	3	1				> 4(2.5-6 Hz)	1		C
76	Kushk-Nosrat	4	1				> 4(0.7-1.5 Hz)	4	4-10 (1st 10 m)	A1
77	Lahijan	4	1	Clay and silt	264	-4(0.8-2 Hz)	3-4(0.8-1.5 Hz)	4		C
78	Lali	3	8				> 4(3-5 Hz)	2		C
79	Lamerd	1	1				2-3(0.8-10 Hz)			C
80	Lar -Fars	1	2				1-2(4-15 Hz)	2		C
81	Lendeh	1	1				2-3(1.5-2 Hz)	2		C
82	Mahan	4	1				> 4(0.1-1.5 Hz)	2		C
83	Maharloo (PTT)	1	1				2-3(1.5-6 Hz)	1		B
84	Maku	2	4	Soft alluvium in surface	652		3-4(4-8 Hz)	2	13-60 (1st 22 m)	A1
85	Manjil	2	7	Fine gravel in surface	589	2-3(6-11 Hz)	> 4(5-7 Hz)	3		C
86	Maraveh-Tappeh	3	1				> 4(3-6 Hz)	2		C
87	Masal	3	3				3-4(2.5-7 Hz)	3		C
88	Mashad (Sakht-Azma)	4	1				3-4(0.5-2.5 Hz)	3		C
89	Masjed-Soleyman	3	1				> 4(2.5-5 Hz)	1		C
90	Minab	1	2				2-3(1.5-5 Hz)	3		C
91	Musian	3	2				> 4(2.5-6.5 Hz)	2	6-200 (1st 25 m)	A1
92	Naghan	1	16	Soft alluvium in surface	768	1-2(0.2-25 Hz)	1-2(1-20 Hz)	1		C
93	Namin	3	2				> 4(3.5-7 Hz)	1		C
94	Nir (Ardebil)	3	2				3-4(2-6 Hz)	4		C
95	Noorabad-Mamassani	3	5				> 4(3.5-5 Hz)			C

Table 1 (continued)

No	Station	Site categorization	Number of records	Site geology	Vs over 1st 30 m (m s ⁻¹)	Amplification of H/V on microtremors	Amplification of H/V on strong motions	Site based on surface geology (BHRC)	Electric resistivities (ohmm)	Q
96	Old Lar	1	1				1-2(3-10 Hz)	2		C
97	Pol-Sefid	4	3				> 4(0.2-3 Hz)	3		C
98	Rasht (Housing Bureau)	3	2	Cohesionless gravel		1 2(0.6-3 Hz)	> 4(2-4 Hz)	3		B
99	Rasht (University)	3	1	Thick fine gravel		1 2(0.2-5 Hz)	> 4(2-2.5 Hz)	2		B
100	Ravar	3	1	Soft soil in surface		1 3(0.2-3 Hz)	3-4(1.5-3.5 Hz)	2		B
101	Rayen	1	1	Soft soil in surface		1 2(0.6-20 Hz)	1-2(0.2-7 Hz)	2		B
102	Robat-Karim	1	1	Coarse grain gravels		1 3(0.6-1.5 Hz)	1-2(0.2-2 Hz)	2		C
103	Roshkhar	1	2				1-3(0.8-5 Hz)	4		C
104	Rudbar	3	22	Cohesionless river gravels	339	1-3(3-7 Hz)	> 4(3.4-5.5 Hz)	3	4-20 (1st 16 m)	A1
105	Rudsar	4	1	Sand beach of Caspian sea	215	1 2(0.4-25 Hz)	> 4(0.25-0.7 Hz)	3		A2
106	Rudshur	4	1	Silt and clay in surface			3-4(7-1.5 Hz)	3		C
107	Saadabad (Borazjan)	1	7	Fine gravel in surface	958	1 2(0.2-2 Hz)	3-4(2.5-9 Hz)	1		A2
108	Saman	2	1				> 4(5-11 Hz)			C
109	Sarbaz	2	1				> 4(4.5-6 Hz)	4		C
110	Sedeh	3	4	Silt and clay in surface		2-3(4- Hz)	3-4(3-4 Hz)	2		B
111	Sefidabeh (School)	2	1	Hard gravels			> 4(5.5-8 Hz)	2		C
112	Sefidabeh (Microwave)	1	1	Sandstone and shale			2-3(1.5-7 Hz)	1		C
113	Seifabad (S. Kazerun)	1	1				1-2(0.8-1 Hz)	1		C
114	Selseleh	3	1				> 4(3-5 Hz)	3		B
115	Shabankareh (Borazjan)	4	37	Silty sand in surface	337		3-4(3-6 Hz)	3		C
116	Shabastar	1	3				2-3(2-9 Hz)			C
117	Shahid Yaaghubi Dam (S. Mashhad)	3	1				> 4(3-7.5 Hz)			C
118	Shalamzar	3	2				> 4(3-5 Hz)	4		C
119	Shiraz	4	1	Silt and clay in surface		-4(0.5-1 Hz)	> 4(0.2-1.1 Hz)	2		B
120	Siah-Cheshmeh	1	3				2-3(4-8 Hz)	4		C
121	Silvaneh	4	1				> 4(0.7-3 Hz)			C
122	Sirch	1	1	Fine gravel in surface		-2(0.8-6 Hz)	2-3(0.2-15 Hz)	3		B
123	Sisakht	1	4				2-3(7-10.5 Hz)			C
124	Tabas	1	9	Fine gravel in surface	715	-2(0.2-25 Hz)	2-3(1-15 Hz)	2	10-130 (1st 21 m)	A1
125	Talesh	3	5	Clay-silty gravel	514	-3(0.6-2 Hz)	3-4(0.8-4.5 Hz)	4	10-100 (1st 28 m)	A2
126	Tasuj	2	1				> 4(6.5-8 Hz)			C
127	Taybad	4	1				> 4(0.3-0.5 Hz)	3		C
128	Tehran (BHRC)	1	1	Coarse grain gravels		1-2(0.6-15 Hz)	2-3(2-3 Hz)	2		D
129	Tehran (Chizar)	1	1	Coarse grain gravels		1-3(1-4 Hz)	1-3(0.3-5 Hz)	3		C
130	Tehran (Sharif University)	1	1	Fine gravel in surface		1-2(0.6-7 Hz)	1-2(2-3 Hz)	2		D
131	Tonkabon	4	1	Artificial soil	209		> 4(1.5-2.5 Hz)	3	4-21 (1st 25 m)	A2
132	Torbat-Heydarieh (SH)	3	1				> 4(2-4 Hz)	2		C
133	Torbat-Jam	1	2				1-2(3.5-9 Hz)	4		C
134	Vendik	2	10	Fine gravel in surface	597	1-2(0.2-20 Hz)	> 4(8-15 Hz)	3	2.5-100 (1st 27 m)	A2
135	Zanjan	1	1				2-3(1.5-5 Hz)	3		C
136	Zanjiran	2	36	Fine gravel in surface	672	1-1.5(0.3-10 Hz)	3-4(7-11 Hz)	1	10-140 (1st 15 m)	A2
137	Zarrat (school)	1	30	Fine gravel in surface	704	1-3(0.2-8 Hz)	3-4(3-7 Hz)	1	5-30 (1st 7.5 m)	C
138	Ziaratali -N. BandarAbbas	1	1				2-3(3-10 Hz)			C

In all of the sites, the obtained strong motion records are studied to obtain their horizontal to vertical spectral ratio (receiver function for the strong motions; RF SMS). Calculating the same ratio for microtremors (H/V ratio for the microtremors; H/V MTS), we have been able to compare the H/V ratio for noises and earthquakes. No geotechnical boring was done through this study, and no data of this type was found in the location of the stations.

Here we have tried to determine the degree of coincidence between different methods of site characterizations. This comparison and likely coincidence were possible especially in sites where we had results from all methods. Finally we describe the factors that may have some affections on site amplifications (besides site geology) which could alter our site characterization results.

3.3 An overview on the general situation of the sites and the tests

The locations of each selected site are shown in Figure 3.1. The sites are mostly located in the western and northern Lut area (in central-east Iran), the western Alborz Mountains and the central Zagros region, which correspond to areas hit by the largest events over the last 22 years.

The shear wave velocities in deep layers can not be found by the geoseismic tests; the effective investigation depth for the geoseismic tests is about 30 to 35 meters. The microtremor tests have been proposed, mainly in Japan, to provide some information on site conditions since seismic noise contains surface and body waves which are filtered by surface layers. The geoelectric tests may distinguish very grossly between rock and soil types within a depth of a few tens metres. The results from the geoelectric tests give a range of electric resistivities depending on the ionization of the soil particles. The characteristic resistivities for fine and coarse grain alluviums may juxtapose a lot. It is therefore very difficult to distinguish between different types of sites through the geoelectric tests. Based on the aforementioned reason the results of geoelectric tests will neither be presented here nor be used in the site categorization.

In the absence of down-hole arrays and rock outcrop motions, we have used the H/V method having then an idea of the response of each site to a strong ground motion.

Most of the strong motion sites in Iran are installed on foothills, for the sake of better climate and topographic situations in most areas of the country. On the other hand, in most cases, the sites are alluvial or firm grounds, and the soft soil sites may be found only near the coast (Lahijan, Rudsar and Tonkabon) or in the plains (Talesh, Golbaf, Shiraz and south

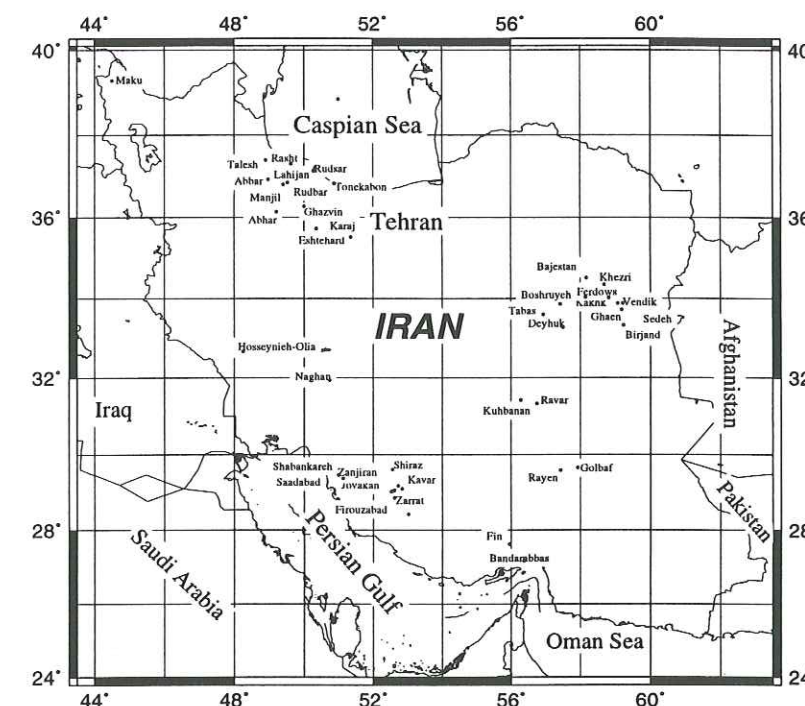


FIG. 3.1 – The locations of the stations which are studied and presented in this paper.

Tehran). A summary of the tests performed in each of 50 sites is presented in table-I. As is shown in the table, in most of these sites a microtremor test was done and in each the local geological situation was observed. The comparison of the local geological observations with the results of the tests may show us the degree of reliability of these observations in each place.

3.3.1 Receiver function method for strong motions

Since there are no station pairs located one on soil and another on rock in a nearby distance, and as there is no down-hole array in the country, we had to use single-station estimates of H/V ratio for site effects. This method, also called the receiver function technique, has been shown to be efficient (Theodulidis et al., 1996, Riepl et al. 1998), in pointing out the site fundamental frequency, and its stability makes it applicable, in principle, even when one single three-component recording is available. The formulation used for the H/V method is based on the spectral ratio (R_{hv}) between the smoothed horizontal components and the smoothed vertical component:

$$R_{hv} = \frac{\sqrt{\frac{S_{H1}^2}{2\sqrt{T_{H1}}} + \frac{S_{H2}^2}{2\sqrt{T_{H2}}}}}{\frac{S_v(f)}{\sqrt{T_v}}} \quad (3.1)$$

where T_{H1} , T_{H2} and T_V are the signal duration for the horizontals and vertical components respectively. Since the same time windows are used the same for all of the components, this relationship might be simplified as;

$$R_{hv} = \frac{\sqrt{\frac{1}{2}S_{H1}(f)^2 + S_{H2}(f)^2}}{S_V(f)} \quad (3.2)$$

In this study, this ratio was considered to be significant only when the signal to noise ratio R_{sn} for both components exceeds a given threshold value, taken equal to 3. The signal to noise ratio (R_{sn}) is computed as:

$$R_{sn} = \frac{\frac{S(f)}{\sqrt{t_s}}}{\frac{N(f)}{\sqrt{t_n}}} \quad (3.3)$$

where t_s and t_n are the window duration for the signal and noise parts, respectively. A R_{sn} ratio over 3 is selected as the proper ratio to distinguish the signal from the noise. The resultant R_{sn} ratios for two horizontal components are compared with the same ratio calculated for the vertical component in different frequencies.

The implied smoothing is the smoothing proposed by Konno and Ohmachi (1998), which keeps corrects amplitudes whatever the frequency. The stability is found acceptable especially in the sites with many records. The standard deviation of this ratio (RF SMS) is found to be about 1.5. The standard deviations of the digital and the analog records for the RF SMS method are shown in the sites with more than 10 records (Figure 3.2). This figure shows that the standard deviations for the digital records are less than the analog ones, and on the other hand in most cases the standard deviations do not pass 2. Therefore it may be concluded that the use of RF SMS as the main criteria to distinguish the site responses was reliable.

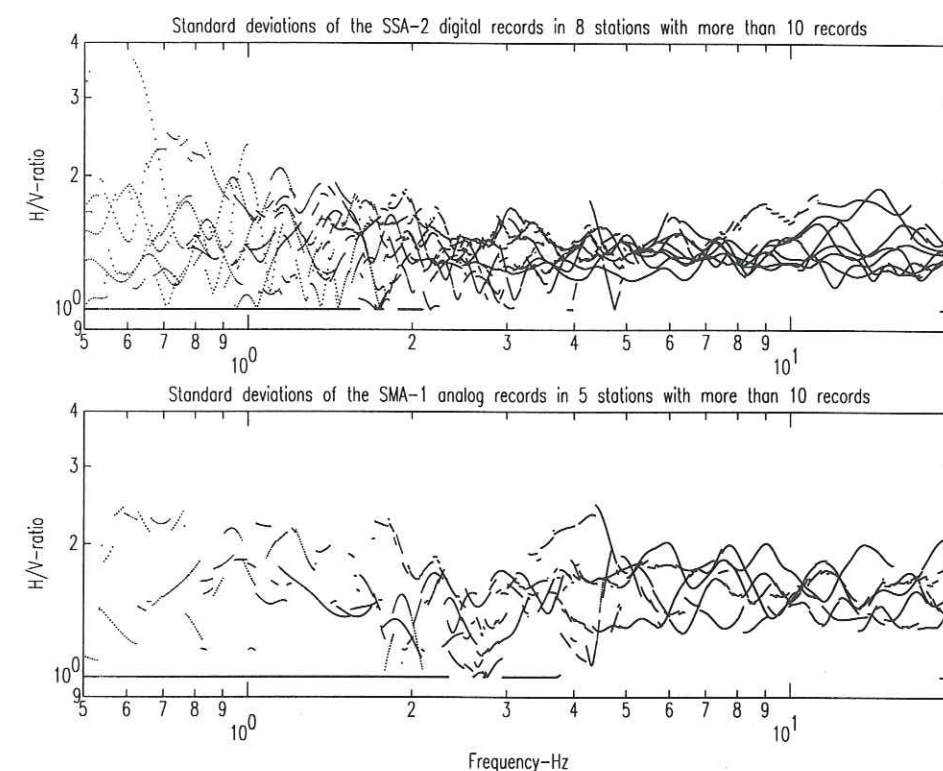


FIG. 3.2 – The comparison of the standard deviations for the digital (SSA-2; a) and analog (SMA-1; b) recorders in the sites with more than 10 records.

3.3.2 Microtremors

The microtremor tests are performed in 47 sites, using SSR-1 sensors with a minimum sensitivity of 0.1 Hz. Five windows of 3 minutes duration are selected in each site. In each coordinate, only the best stationary parts of the tremors are considered. The spectral ratio (R_{hv}) formulation for the microtremors are the same as the strong motions. The H/V MTS are compared in each site with the relative RF SMS.

3.3.3 Geoseismic tests

The geoseismic tests in 26 sites displayed the compressional and shear wave velocities in the superficial first 30 meters of depth using the refraction method. The theoretical transfer function (TTF) could then be computed in each case with 1D programs based on the geoseismic results in each case. There were some cases where the S wave velocities at depth were low (Golbaf, Lahijan). In these cases no velocity contrast may be seen in these depths, meanwhile the receiver function showed the amplifications in low and middle frequencies. No damping measurement

was done at the studied sites.

Since it is necessary to place a row of 24 geophones with the interval distances of 4 to 5 meters to do the geoseismic tests, and according to the location of the stations which are mainly in the central parts of the cities, the tests were not always possible to be done in the same place of the stations. In these cases we have tried to do this test in the nearest possible place. Therefore the velocity profile tests in Deyhuk, Firouzabad, Ghaen Ghazvin, Golbaf, Kavar, Rudbar, Rudsar, Saadabad, Shabankareh, Tabas, Tonkabon and Zarrat are performed in the distances of 200 to 1000 meters away from the location of strong motion accelerographs. This problem might be the source of the incoherence between the strong motion and geoseismic results. The rest of the tests are performed in the distances of less than 200 meter too the stations.

3.4 The results of the geoseismic tests, microtremors and H/V for Strong Motions

For twenty-six sites shown in Figure 3.1, some information from the receiver functions, the noise recordings, and the velocity profiles could be simultaneously found from which a theoretical 1D-transfer function for vertically incident S waves could be computed. It has been tried to consider the sites where the most important earthquakes were recorded. Meanwhile, in three sites (Maku, Shabankareh, Tonkabon) a reliable results have not been obtained on the vertical component, and thus the microtremor results were eliminated. In 23 other sites, only performed microtremor test were performed in order to compare them with RF SMS. For some of the sites, a good consistency between all three techniques could be observed, while for some others the agreement was not so close. In particular, the noise results were very disappointing compared with studies made in other countries (Riepl et al., 1998; Duval, 1994; Bard et al., 1997, Lachet et al. 1996).

3.4.1 Sites with a satisfactory agreement between the results of the different methods

A satisfactory similarity between the different methods was obtained only for less than one half of the studied sites. The sites with the best similarities for the different tests are, for instance, Fin (Figure 3.3), Firouzabad (Figure 3.4), Ghaen (Figure 3.5), Jovakan (Figure 3.6), Lahijan (Figure 3.7), Manjil (Figure 3.8), Naghan (Figure 3.9), Rudbar (Figure 3.10), Tabas

(Figure 3.11) and Zanjiran (Figure 3.12). This means that the factors affecting the amplifications were very different. In almost all cases, the peaks on the H/V MTS had low amplitude, much lower than those of the H/V ratio strong motion spectra (RF SMS) and the theoretical transfer functions (TTF). However poor agreement was observed at Lahijan (Figure 3.7) between RF SMS and TTF because the S wave velocity profile was not deep enough. The presence of the low velocity surface layer was essential to find a satisfactory agreement between methods.

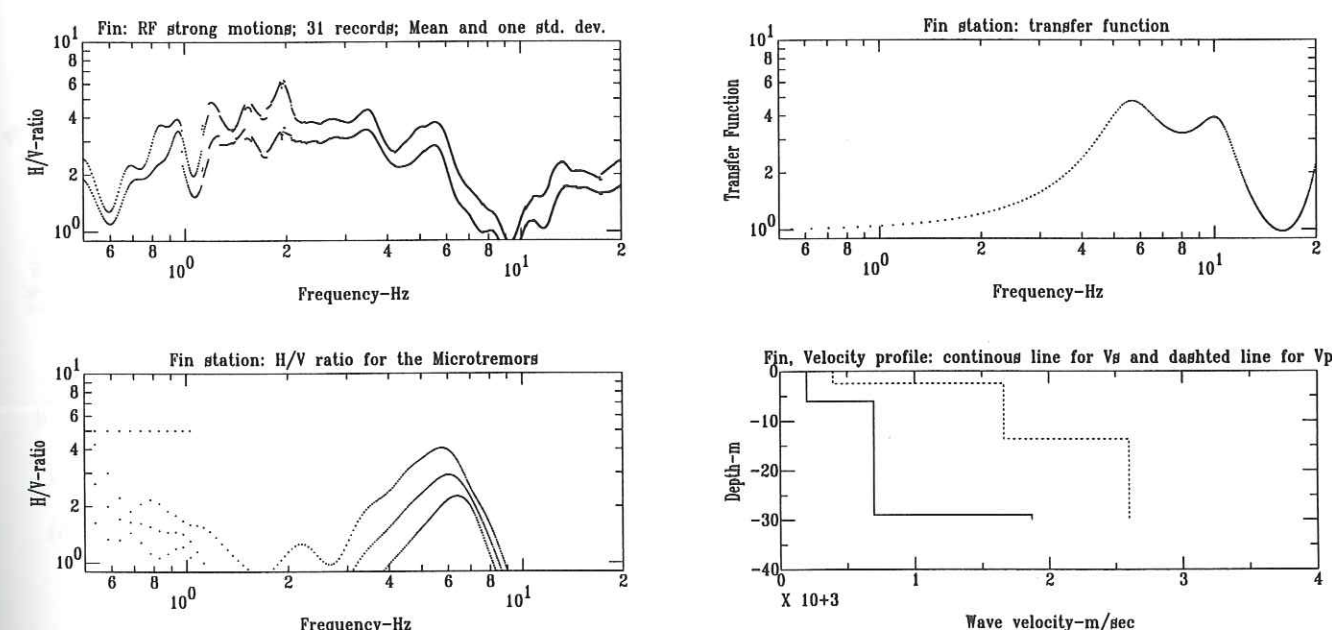


FIG. 3.3 - The results of the site tests in Fin (North Bandarabbas) station (RF SMS, H/V MTS, transfer function and velocity profile).

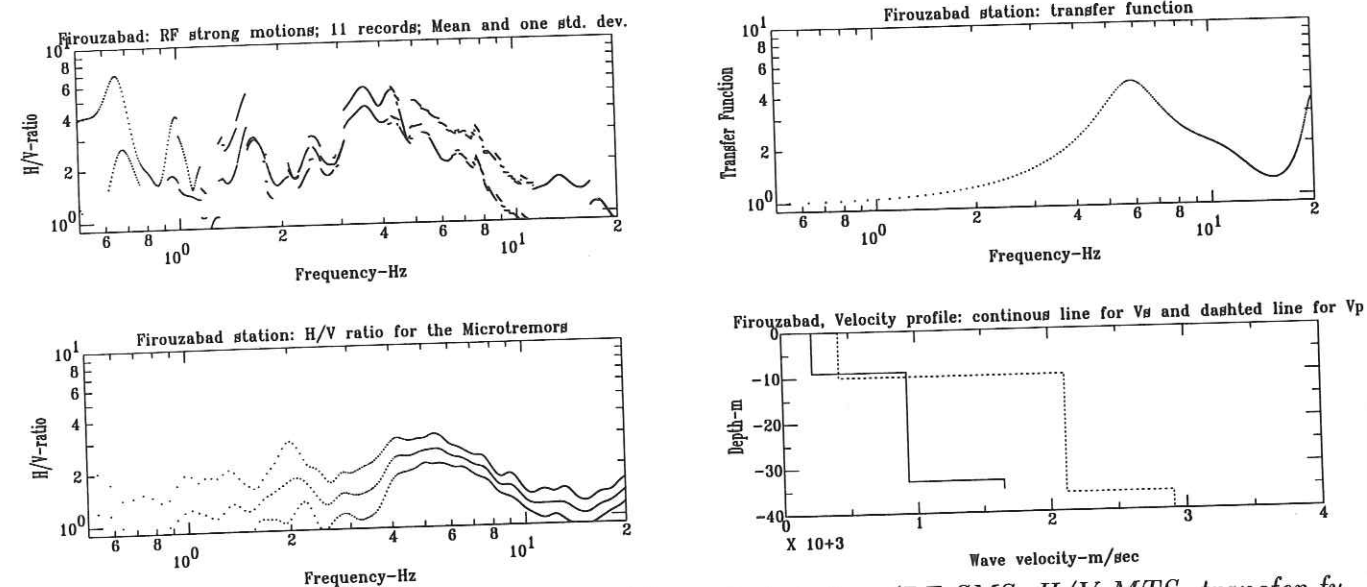


FIG. 3.4 - The results of the site tests in Firouzabad station (RF SMS, H/V MTS, transfer function and velocity profile).

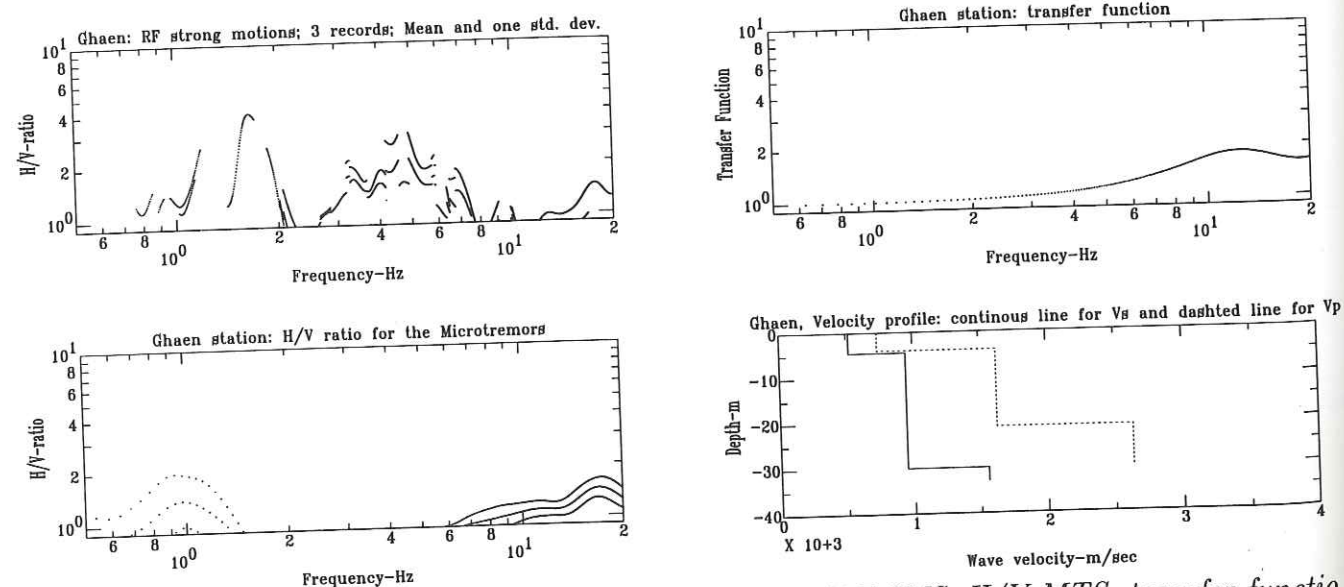


FIG. 3.5 - The results of the site tests in Ghaen station (RF SMS, H/V MTS, transfer function and velocity profile).

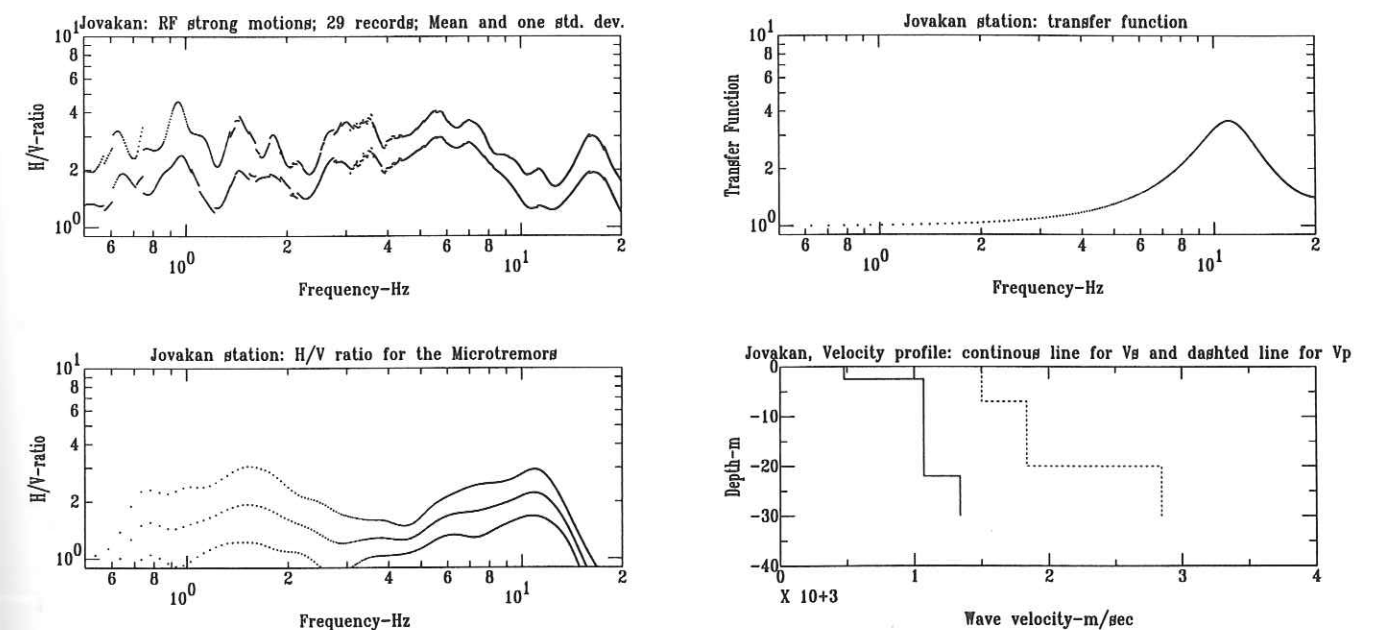


FIG. 3.6 - The results of the site tests in Jovakan station (RF SMS, H/V MTS, transfer function and velocity profile).

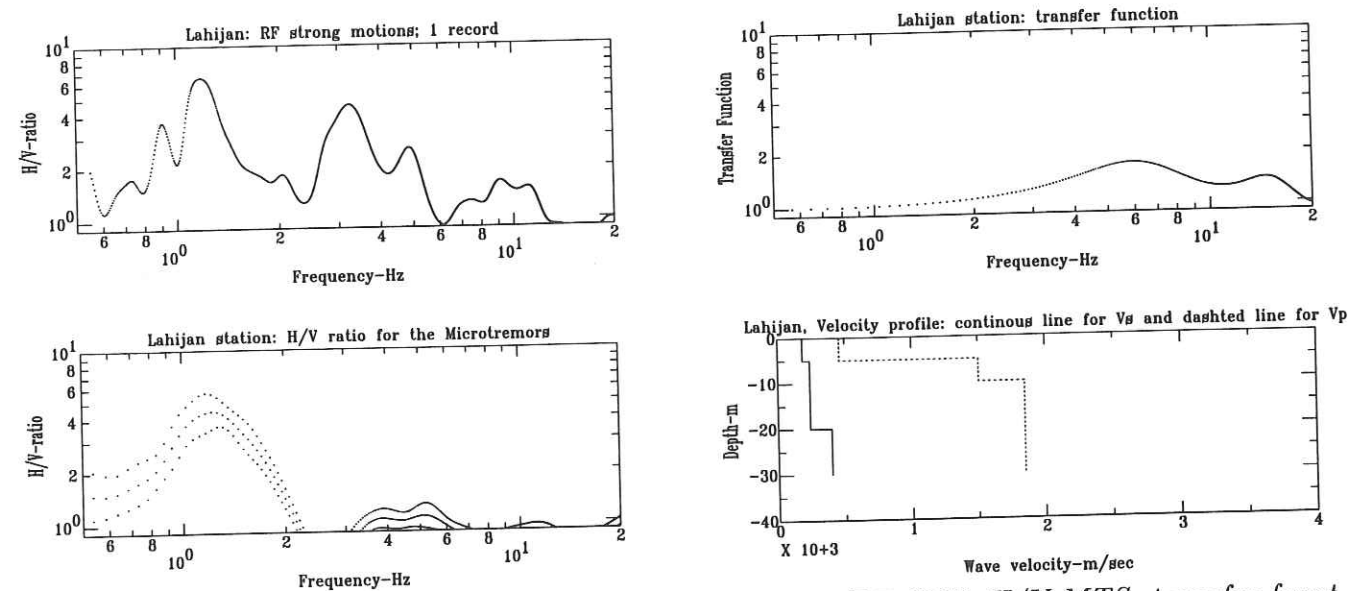


FIG. 3.7 - The results of the site tests in Lahijan station (RF SMS, H/V MTS, transfer function and velocity profile).

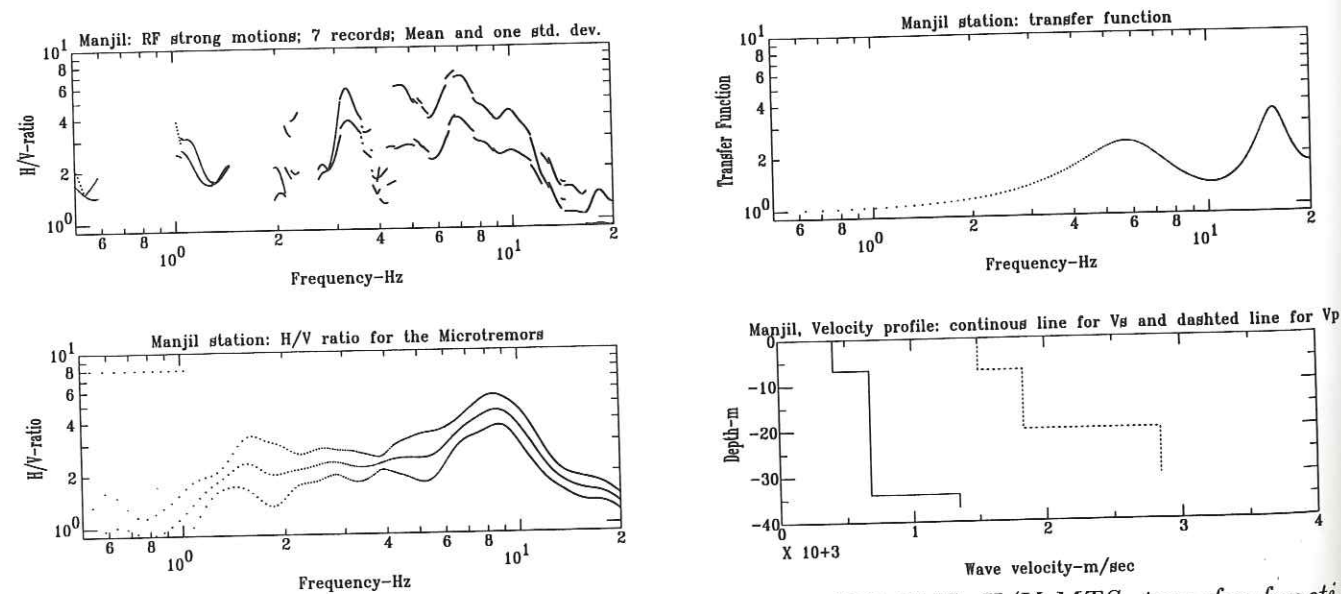


FIG. 3.8 - The results of the site tests in Manjil station (RF SMS, H/V MTS, transfer function and velocity profile).

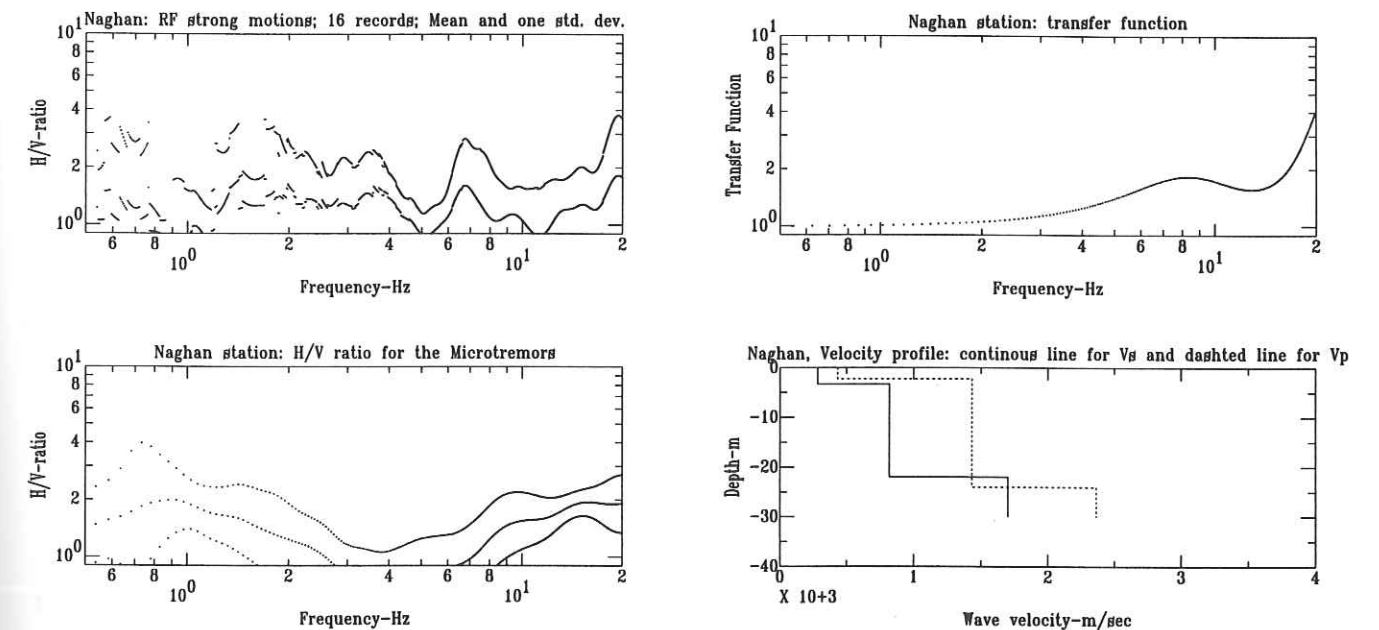


FIG. 3.9 - The results of the site tests in Naghan station (RF SMS, H/V MTS, transfer function and velocity profile).

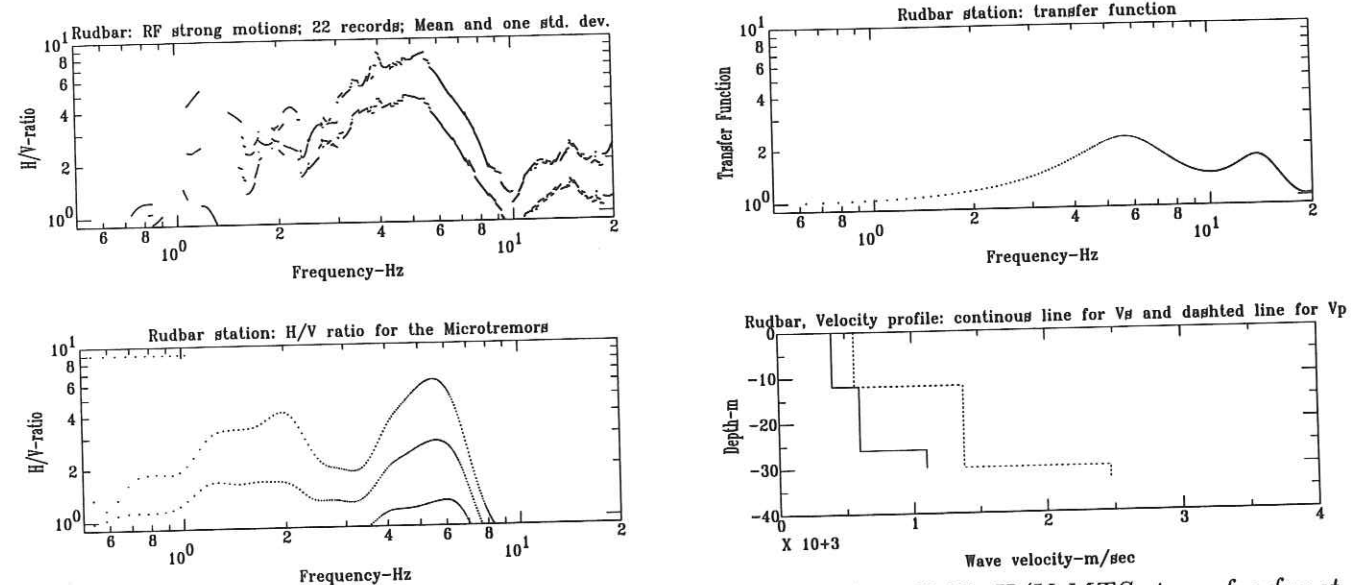


FIG. 3.10 – The results of the site tests in Rudbar station (RF SMS, H/V MTS, transfer function and velocity profile).

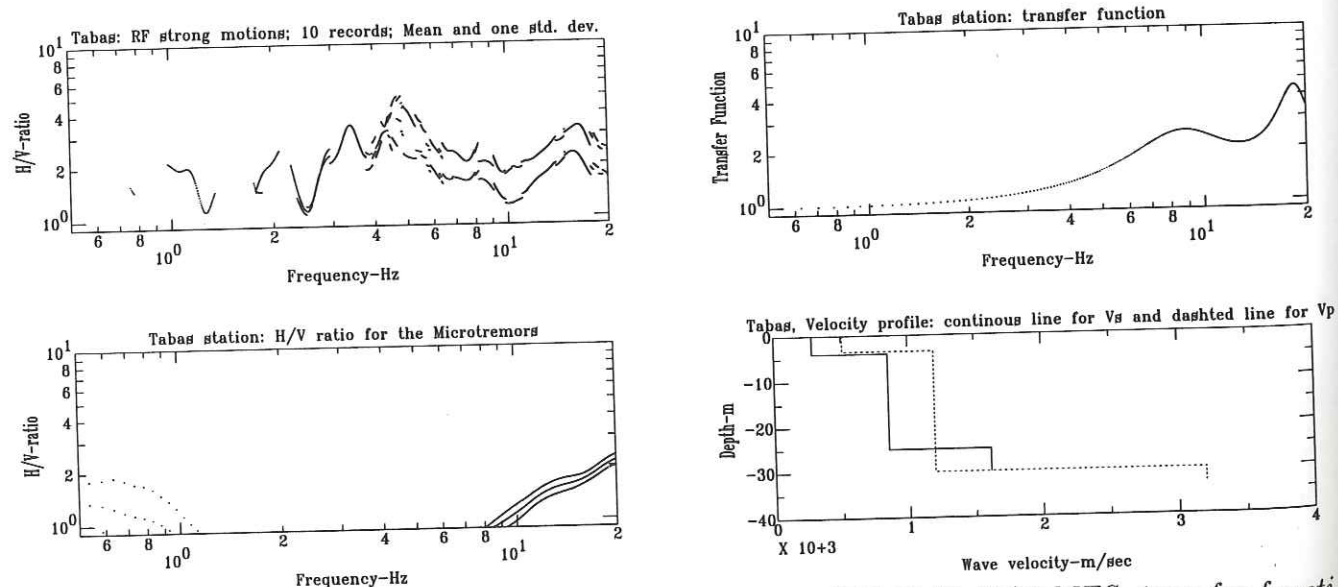


FIG. 3.11 – The results of the site tests in Tabas station (RF SMS, H/V MTS, transfer function and velocity profile).

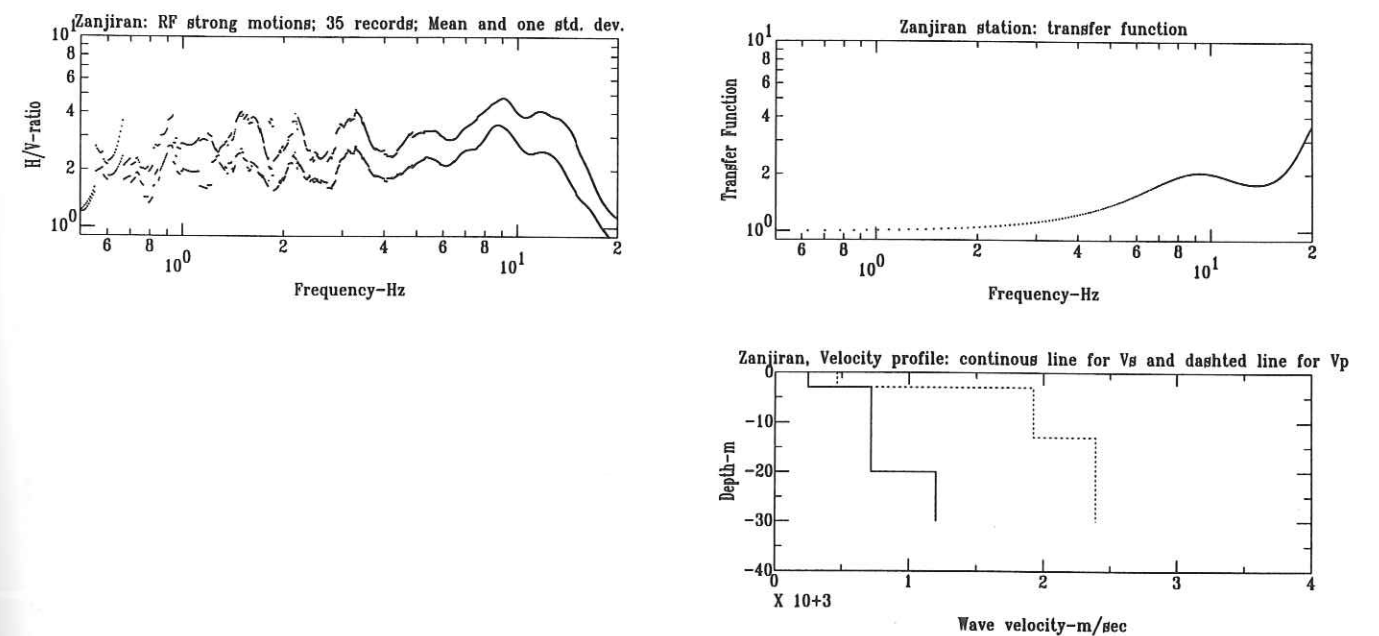


FIG. 3.12 – The results of the site tests in Zanjan station (RF SMS, transfer function and velocity profile).

3.4.2 Sites without agreement: failure of the microtremor technique

Based on the present studies, the results of the microtremor test appear to be reliable just for sites exhibiting significant amplifications at low and/or intermediate frequencies (less than 5 Hz) caused by a low velocity superficial layer. In some of the sites the thick alluvium deposits cause the amplifications in low and middle frequencies (less than 5 Hz) on RF SMS, which the H/V MTS did not exhibit the same peaks, for instance in Ghazvin (Figure 3.13). In Rudsar (Figure 3.14) the velocity the transfer function has not shown the peaks in low frequencies (evident on RF SMS). In the soft soil sites, it seems that a high contrast in the superficial layers is needed to cause the evident amplifications in H/V MTS. For example in Golbaf (Figure 3.15) which shows a low average velocity in the first 30 meters (439 m/s) the amplifications on the RF SMS may not be seen on the same spectra for the microtremors. A high contrast in about 40 metres depth, with a V_s velocity of about 1500 to 200 m/s is might be sufficient to explain this low frequency amplification in RF SMS in this site.

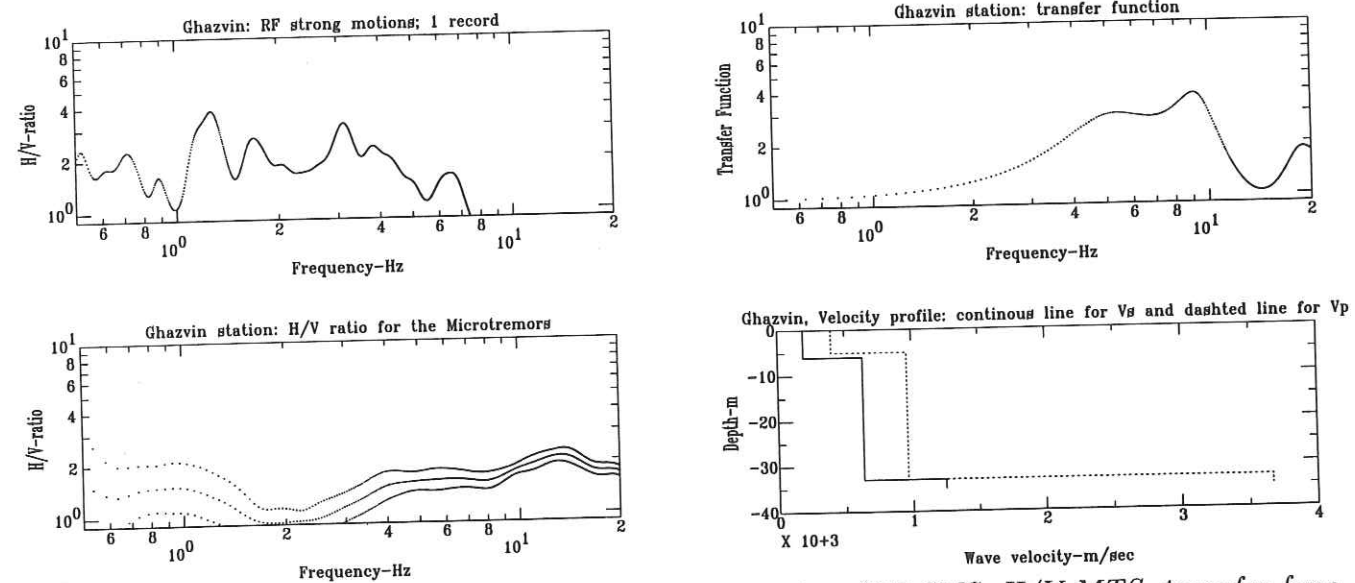


FIG. 3.13 – The results of the site tests in Ghazvin station (RF SMS, H/V MTS, transfer function and velocity profile).

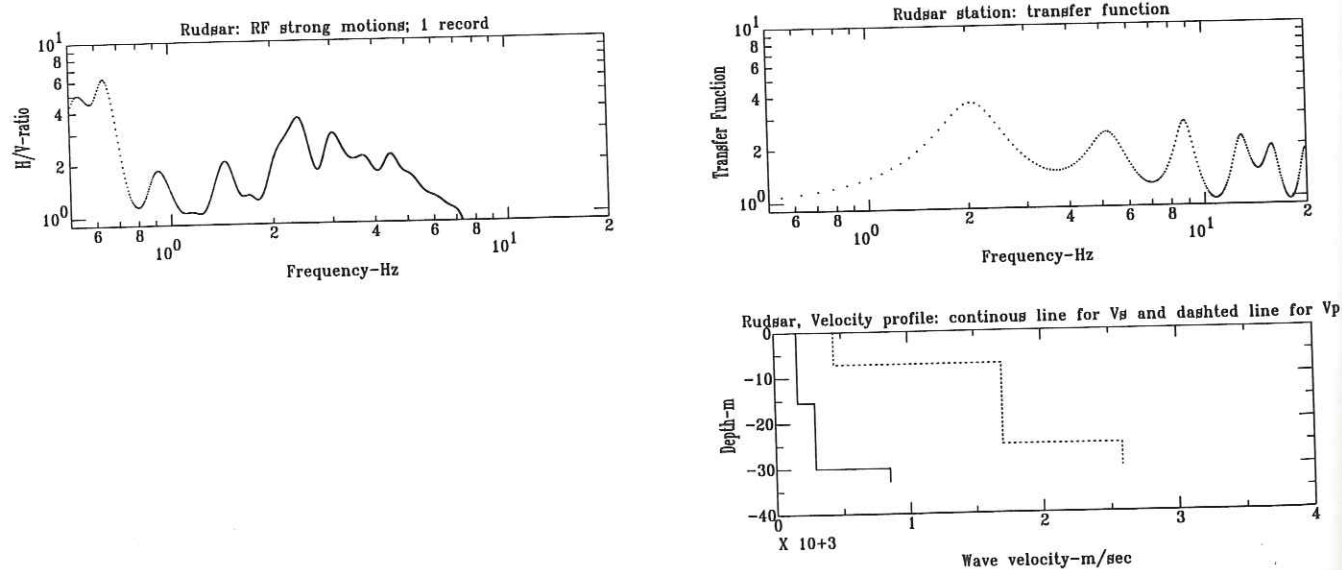


FIG. 3.14 – The results of the site tests in Rudsar station (RF SMS, transfer function and velocity profile).

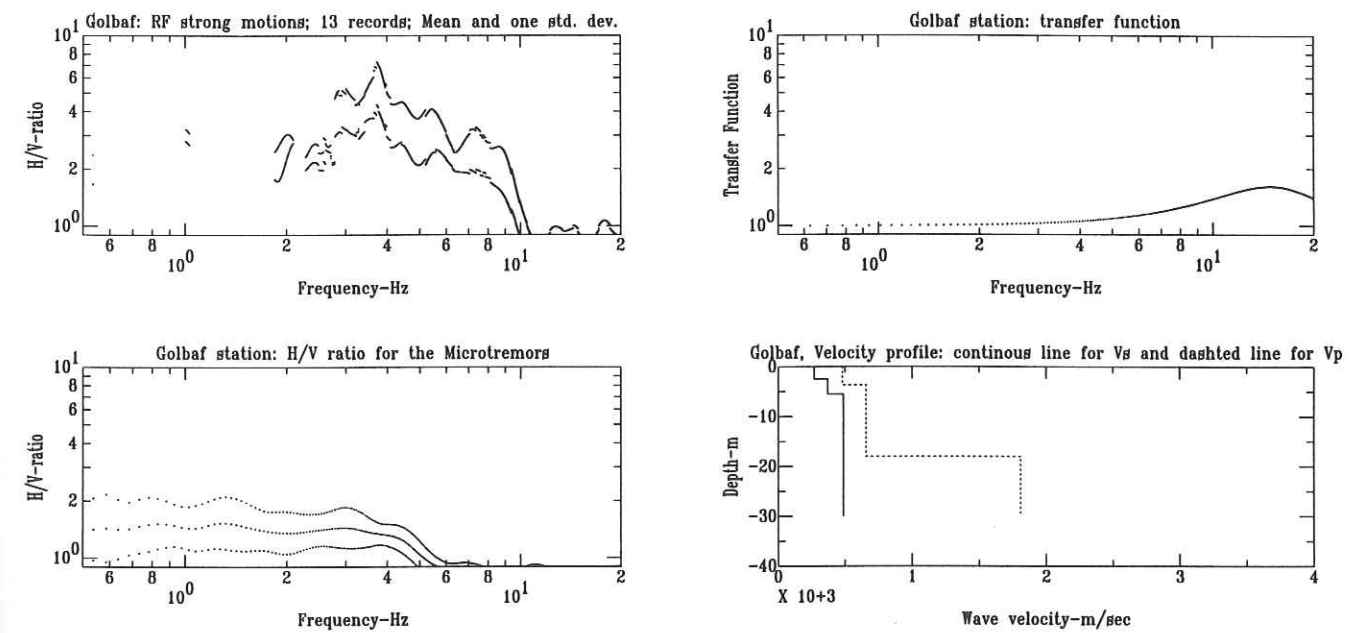


FIG. 3.15 – The results of the site tests in Golbaf station (RF SMS, H/V MTS, transfer function and velocity profile).

There are cases for which there were not each result, however it was possible to compare the amplifications, which may be measured through the H/V MTS and RF SMS. The similarities between H/V ratios for noise and strong motions are observed for instance in Bajestan (Figure 3.16), Sedeh (Figure 3.17), and Shiraz (Figure 3.18). These sites show total accordance between the RF SMS and H/V MTS.

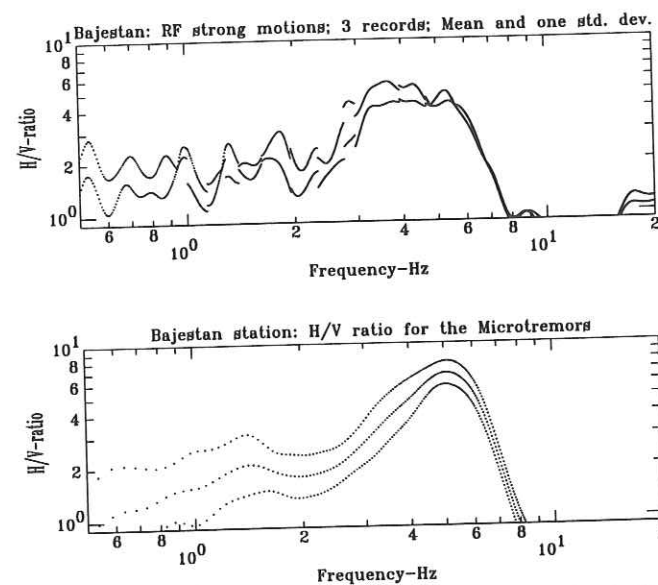


FIG. 3.16 - The H/V ratio results in Bajestan station (RF SMS, H/V MTS).

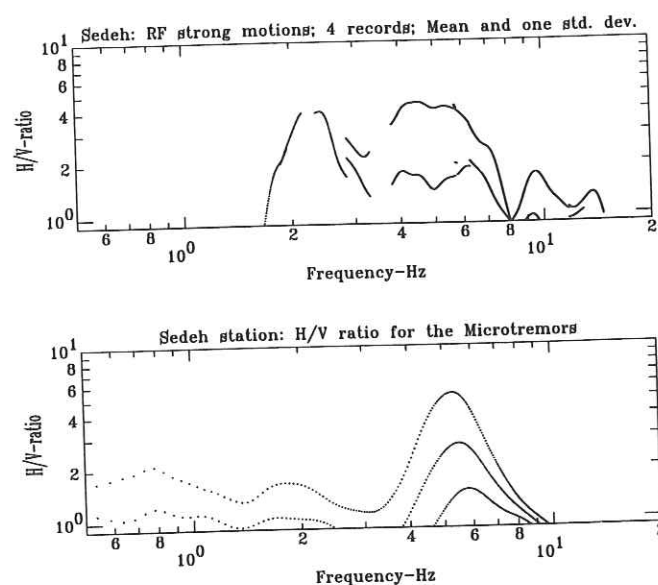


FIG. 3.17 - The H/V ratio results in Sedeh station (RF SMS, H/V MTS).

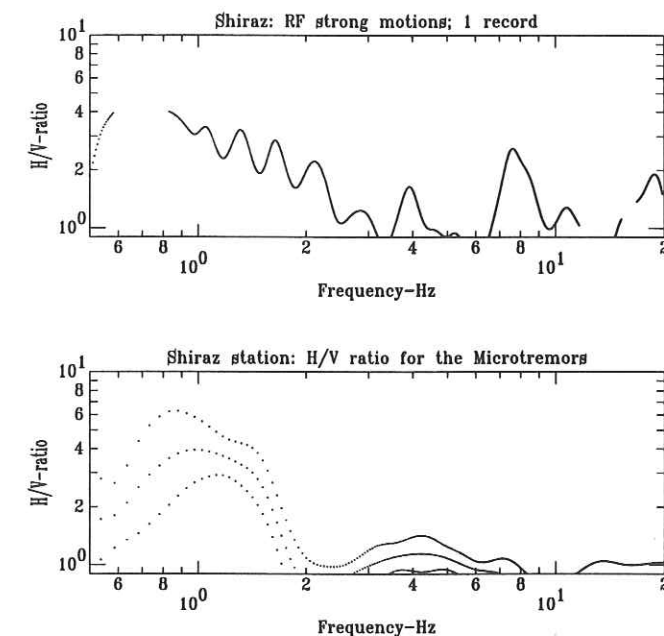


FIG. 3.18 - The H/V ratio results in Shiraz station (RF SMS, H/V MTS).

3.4.3 A preliminary conclusion on the results of the different methods

Among the methods that are used to study the site conditions, the only method that may reveal the site response to ground motions is to study the three component strong motion records (RF SMS). The benefit gained from this method is that we had at least one record in each of the stations and this is the only method that may be applied at each location. On the other hand, the RF SMS is a method that does not have the limitations of the other methods. The velocity profiles measured by the geoseismic methods are limited to the first 30-35 metres; the microtremors have shown the important amplifications just in the soft soil sites, and the geoelectric tests do not give the precise measurements to distinguish the different sites. The study on the amplifications based on the 3 component records has another benefit. In the sites where there are thick alluvial layers on the surface (with a thickness of more than 30 metres) on a very high velocity layer at greater depths, the RF SMS is the only way to observe such amplification in low frequencies. In this case the other methods will show just the high velocity alluvium with some amplifications in high to very high frequencies (more than 15Hz).

In addition, the RF SMS is a very stable method (Figure 3.15)

3.5 A Site Categorization

The relatively good relationship between the S-wave velocity profiles and the RF results allowed us to propose a multi-class site categorization based on the RF curves. This classification is simply based on the amplitude and level of the highest peak on the RF curve:

- * site category #1 corresponds to flat RF curves (i.e., peak amplitude below 3-4), or those presenting a peak with an amplitude larger than 3-4 at frequencies beyond 15 Hz
- * site category #2 corresponds to RF curves presenting a peak with an amplitude larger than 3-4 at frequencies between 5 and 15 Hz
- * site category #3 corresponds to RF curves presenting a peak with an amplitude larger than 3-4 at frequencies between 2 and 5 Hz
- * site category #4 corresponds to RF curves presenting a peak with an amplitude larger than 3-4 at frequencies below 2 Hz

According to these criteria, the 26 studied sites are classified and presented later (see 4.1). The RF curves for these sites of each class are depicted in Figure 3.19.

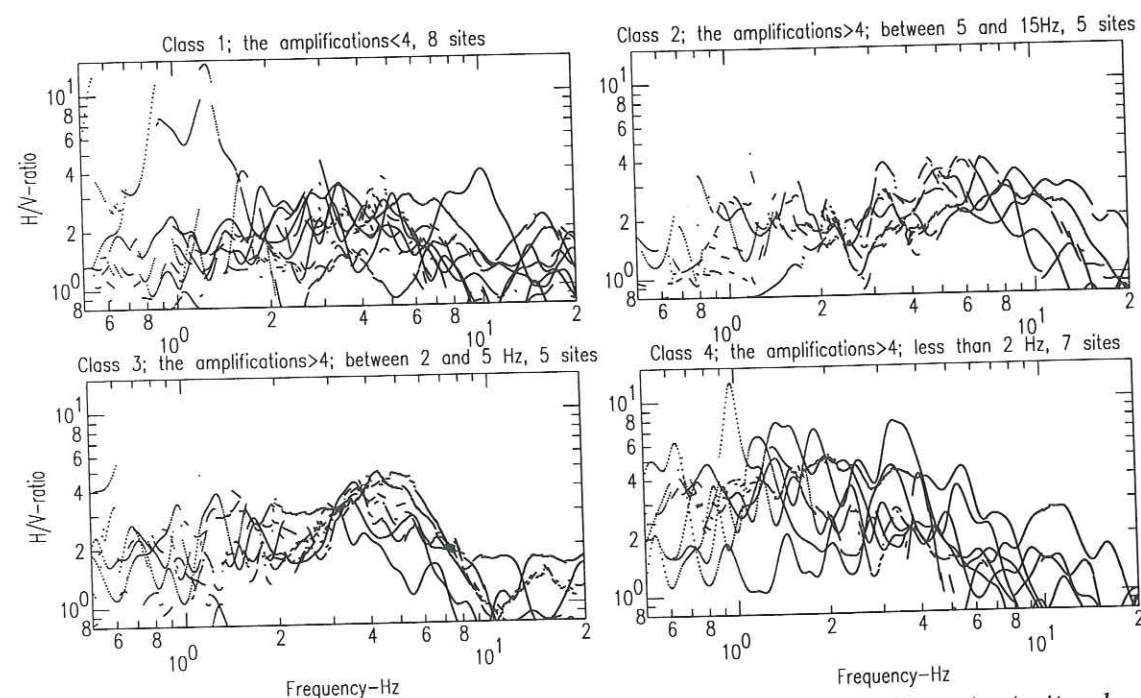


FIG. 3.19 – The comparison of the receiver function for the strong motions in 4 site classes. (the results of 26 sites with the most records).

On the other hand, there are the cases where the RF amplitude is not equal 4 (as it is defined above), but passes 3. In these cases it is tried to observe the results of other tests (if available) to distinguish the site conditions. In such intermediate cases, we have used the V_s and V_p profiles and the microtremor results to decide on the case. However if the peaks did not approach 3 at all, that site is classified as rock site (class 1).

The measured velocity profiles corresponding to each of these classes are grouped in Figure 3.20. The main characteristic of category 1 is that the S-wave exceeds 700 m/s at depths beyond 5 m, although the values may be much lower at very shallow depths (thin layers with resonance frequencies exceeding 15 Hz). On the opposite, the velocity profiles in category 4 exhibit low velocities at surface (below 250 m/s) and at depth (below 500 m/s down to 30 m) except for three "exceptional" sites for which there was a clear discrepancy between velocity profile and RF curve, that we checked several times and could not interpret. Velocity profiles for categories 2 and 3 are intermediate.

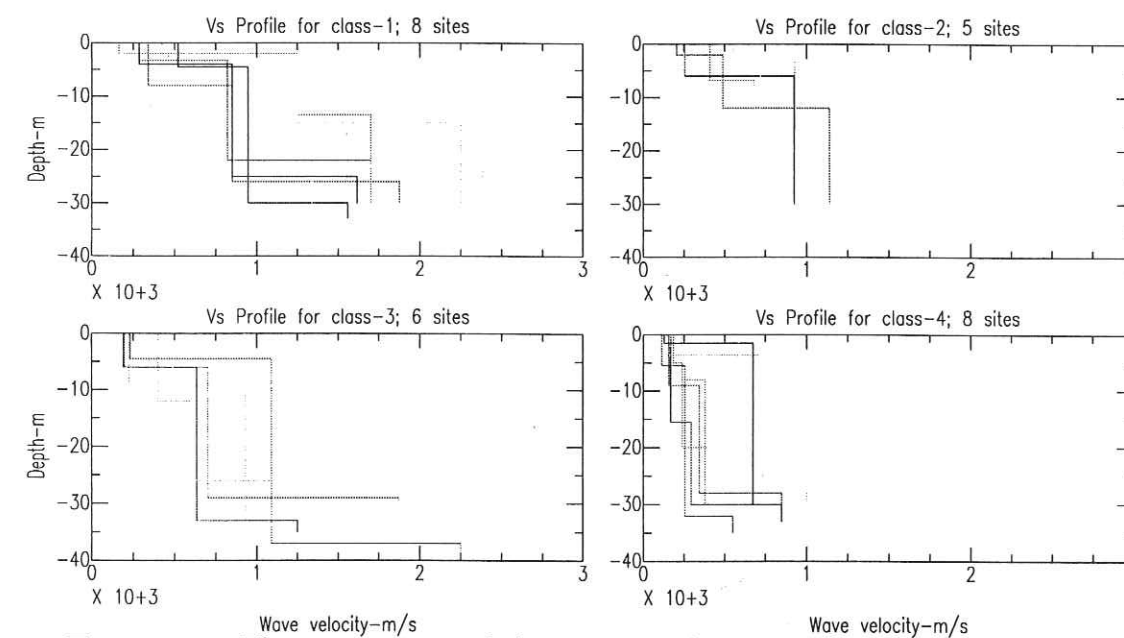


FIG. 3.20 – The comparison of shear wave velocity profiles in 4 site classes.

The microtremor H/V spectra corresponding to each of these 4 categories are displayed in Figure 3.21. It clearly shows that, to the contrary of many published studies, microtremors could not, in our case, point out the fundamental frequency; this negative result may perhaps

be related to the absence of strong impedance contrasts in velocity profiles, except for some class-4 sites. In any case, it requires further work, and probably new measurements, before it can be understood.

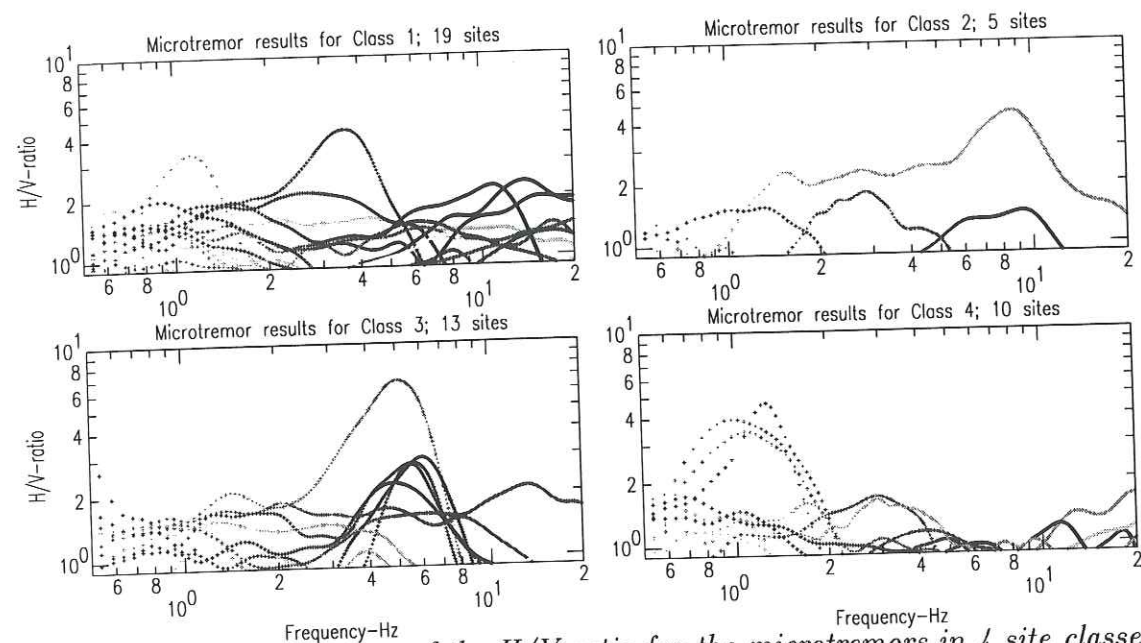


FIG. 3.21 - The comparison of the H/V ratio for the microtremors in 4 site classes.

3.5.1 The Average of V_s for upper 30 meters

The average value of shear wave velocity over the topmost 30 metres has been proposed as a criterion to distinguish the site characteristics in response to the ground motions (Boore et al. 1993, Boore et al 1997, NEHRP 1994). Such a criterion has certainly some drawbacks, since it does not take into account the velocity profile at greater depths, which may have a prominent influence on the low frequency response. However, since there was not any other information for the Iranian sites, the relationship between our site categorization and these average velocities V_{s30} are tested. This average shear wave velocity V_{s30} is defined as:

$$\frac{30}{V_{s30}} = \frac{h_1}{V_{s1}} + \frac{h_2}{V_{s2}} + \dots + \frac{h_n}{V_{sn}} \quad (3.4)$$

with:

$$h_1 + h_2 + h_3 + \dots + h_n = 30m \quad (3.5)$$

The corresponding values for our 26 sites are listed in Table II, and the distribution of V_{s30} for different site classes is shown in Figure 3.22. Although the values at depth are much less reliable than at the near surface, we are rather confident in our estimate of V_{s30} since the "deep" values have only a limited influence in the result. Table II thus points out a rather clear correlation between V_{s30} and our definition for the site classes 1 to 4, based on RF SMS: our criteria on RF SMS may therefore be almost equivalently replaced by the criteria on V_{s30} , as indicated in Table III: the correspondence turns out to be valid for 20 out of our 26 studied sites (i.e., 77% of the cases).

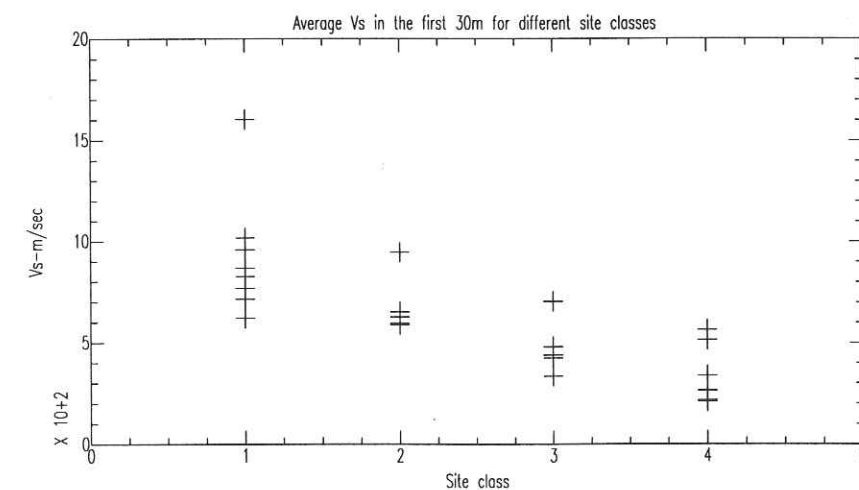


FIG. 3.22 - The distribution of V_{s30} for four site classes.

Table II: Average velocities for each site, in each category

No	Site	class	V_{s30}	No	Site	class	V_{s30}
1	Abbar	1	621	14	Fin	3	480
2	Deyhuk	1	826	15	Firouzabad	3	478
3	Ghaen	1	867	16	Ghazvin	3	424
4	Jovakan	1	1017	17	Golbaf	3	439
5	Kakhk	1	1602	18	Rudbar	3	334
6	Naghan	1	768	19	Zarrat	3	704
7	Saadabad	1	958	20	Abhar	4	263
8	Tabas	1	715	21	Hosseinih	4	563
9	Kavar	2	946	22	Lahijan	4	264
10	Maku	2	652	23	Rudsar	4	215
11	Manjil	2	589	24	Shabankareh	4	337
12	Vendik	2	597	25	Talesh	4	514
13	Zanjiran	2	627	26	Tonkabon	4	209

Table III: The 4 class site categorization

Group	Frequency Band of the Amplification	V_{s30} m/s	Sites
1	$F \geq 15Hz$	$V_{s30} \geq 700$	Abbar, Deyhuk, Ghaen, Jovakan, Kakhk, Naghan, Saadabad, Tabas
2	$5 \leq F < 15Hz$	$500 \leq V_{s30} < 700$	Kavar, Maku, Manjil, Vendik, Zanjiran
3	$2 \leq F < 5Hz$	$300 \leq V_{s30} < 500$	Fin, Firouzabad, Ghazvin, Golbaf, Rudbar, Zarrat
4	$F < 2Hz$	$V_{s30} < 300$	Abhar, Lahijan, Hosseinih, Rudsar, Shabankareh, Tonkabon, Talesh

3.5.2 Discrepancies from the defined criteria

There exist some cases where peaks on RF SMS appear in a frequency band that is not consistent with V_{s30} . The most important reasons for these discrepancies may be considered in different ways. The source effects may in some cases affect the H/V ratio [for instance, when a station was very close to the earthquake source (such as in Tabas)]. In some other cases one may think that a high velocity layer may be found at depths greater than 30 meters, which could not be imaged by geoseismic methods (i.e. for an average surface velocity of 500 m/s there may exist significant amplifications at low frequencies ($f < 1Hz$) if the corresponding thickness exceeds 125 m).

In the Hosseinih-Olia station the peaks on RF SMS were observed in the frequency band of less than 2Hz but the V_{s30} is more than 500m/s (563m/s) (Figure 3.23). The low frequency high amplifications on RF SMS (which may be seen on RF MTS as well) in Talesh (Figure 3.24) and $V_{s30} = 508m/s$ is also inconsistent with the limits observed for most of the other sites. The most important reasons for these discrepancies may be considered in different ways. The source effects may be more effective than site effects, where the station was very close to the earthquake; the Saadabad records which are obtained in the epicentral distances of 8-16 km (Zaré et al 1998) shows low frequency amplifications which may be associated with directivity effects or near field pulses. The high contrast of a superficial low velocity layer with a very higher velocity sub-layer may cause the lower average value of V_{s30} in Hosseinih. There is a superficial layer with $V_s = 130m/s$ and a thickness of 1.5m situated adjacent to a hard sub-layer with $V_s = 672m/s$. In Talesh a high velocity layer might be found at great depth of more than 30 (for a velocity of 730 m/s it might be expected a depth of about 100m to have the amplification of 0.8 to 1Hz). The same situation may be expected for Ghazvin which shows the lower amplifications in 1-2 Hz. If this situation is to be justified with the site effects, a high contrast in a depth of more than 100m is needed.

3.5.3 Application to all Iranian strong motion data

The RF SMS method is performed to determine the site conditions for all of the Iranian strong motion data. The result of this application for 138 site (comprising the studied sites) is shown in Table-1. This criterion is applied to categorize the Iranian sites for which strong motion records are available with satisfactory quality. The final statistics corresponding to the 138 sites is as follows: 51 sites are in class 1 (37%), 22 sites in class 2 (16%), 39 sites in class 3 (29%), and 25 sites in class 4 (18%) (Figures 3.22 and 3.26).

3.5.4 Quality factor for the site determination

To determine the quality of the information that is developed in this study we have used a quality factor in 4 steps ordered from the best to the worst quality: A to D. If there existed all of the data for a site; the "A" quality was assigned. The order is subdivided to A1 for the coordination between the different results, and A2 for the cases when the H/V MTS or the V_{s30} contradicted the RF SMS. Otherwise, when there were not the velocity profiles but there

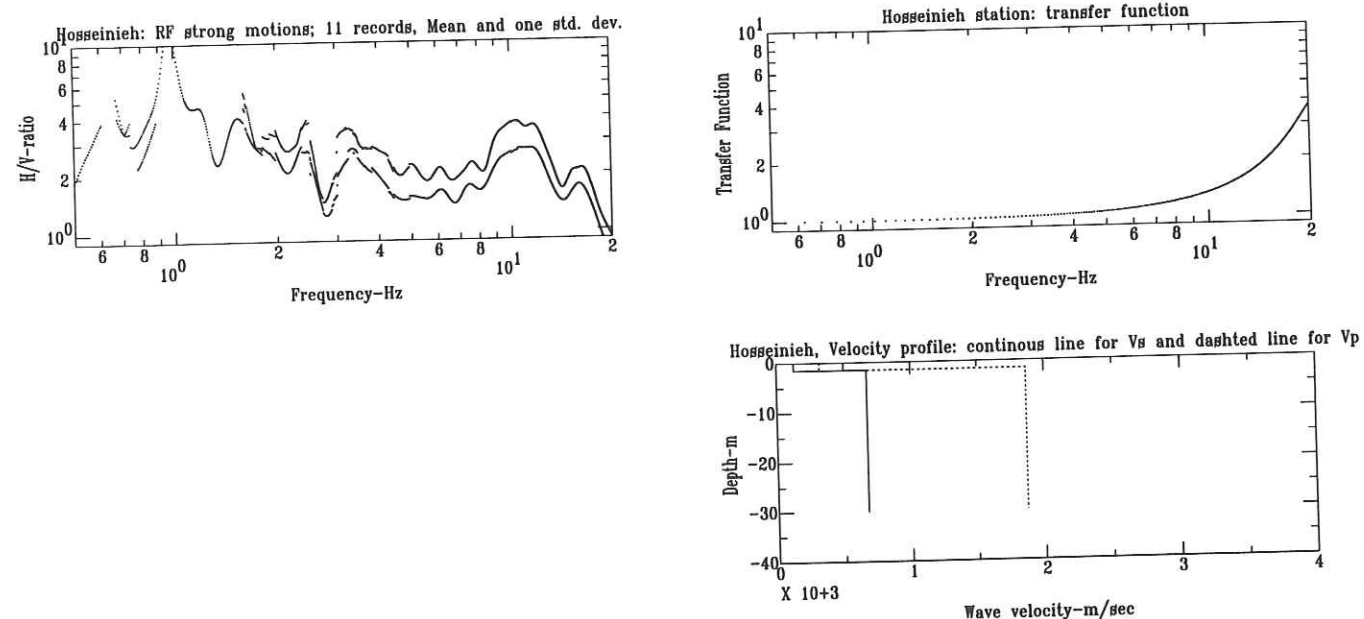


FIG. 3.23 – The results of the site tests in Hosseinieh-Olia station (RF SMS, transfer function and velocity profile).

were all of the other results (H/V MTS and RF SMS) then the "B" quality is marked. If there was just the RF SMS, the "C" is assigned, and in the worst case (when the quality of the record and consequently the quality of the RF SMS was not reliable) "D" is used. These assignments are shown in Table-I.

3.6 Conclusions

We conclude that the 26 sites considered in this study may be grouped in four classes: class 1 corresponds to an average velocity V_{s30} larger than 700 m/s, and no site amplification below 15 Hz; class 2 corresponds to an average velocity V_{s30} between 500 and 700 m/s, and an RF curve exceeding 3-4 between 5 and 15 Hz; class 3 corresponds to an average velocity V_{s30} between 300 and 500 m/s, and a RF curve exceeding 3-4 between 2 and 5 Hz; finally class 4 corresponds to soft sites with an average velocity V_{s30} below 300 m/s, and an RF curve exceeding 3-4 below 2 Hz.

This new record based classification may be compared to the previous 4 class classification

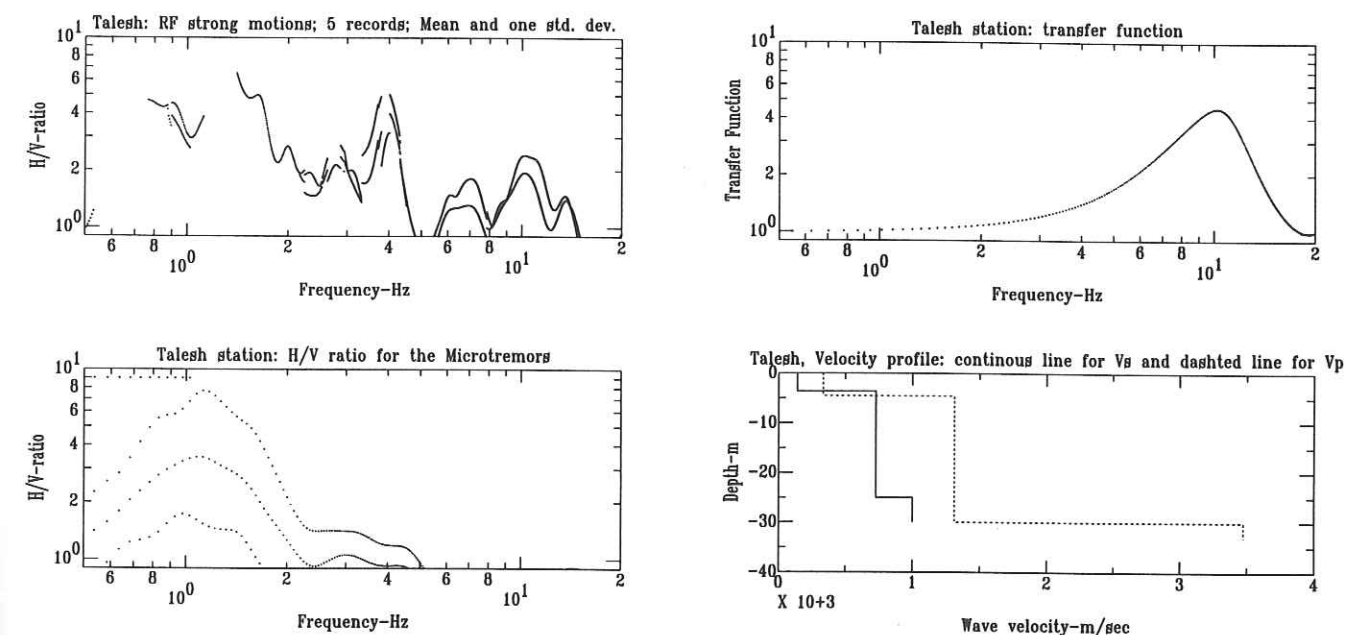


FIG. 3.24 – The results of the site tests in Talesh station (RF SMS, H/V MTS, transfer function and velocity profile).

performed by BHRC (1993) on a pure geological basis: it shows that pure surface geological observations are very poor in assessing the real response of the sites to strong motions. In our study, only in just 22 cases (over the 138 sites; i.e. 16%) the surface geological observations agree with the detailed sites studies (table III, Figure 3.27). In this figure it is shown that the determination of the sites classes based on the surface observation may result in very biased conclusions, such that each site classes may be mistaken for another one.

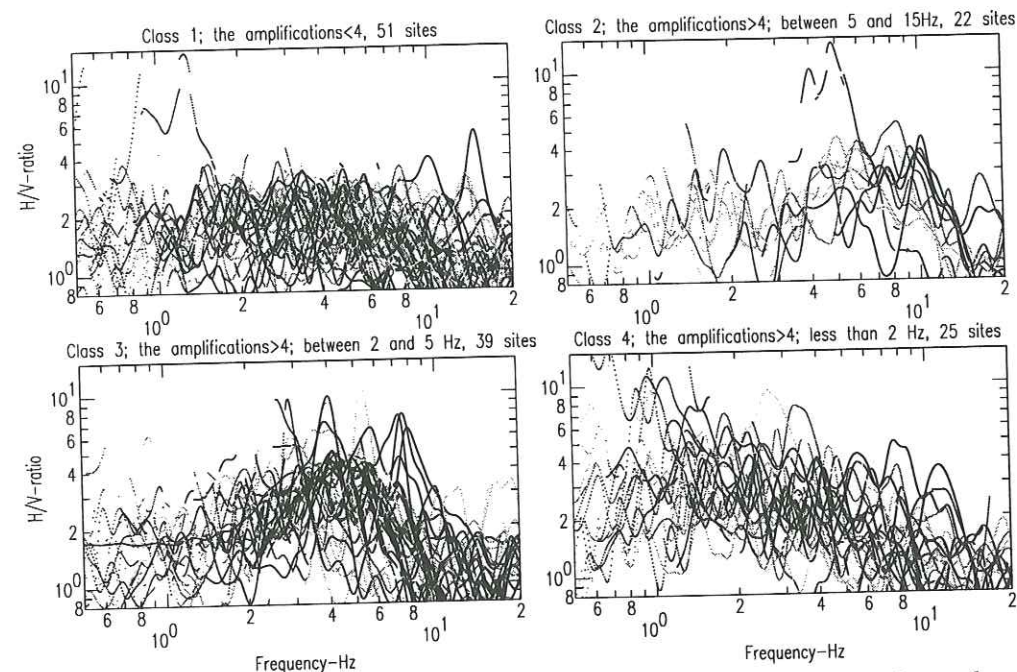


FIG. 3.25 – The results of the RF SMS for all of the 138 sites in four classes.

We insist that the RF SMS method seemed stable for a lot of the studied sites, therefore we have applied this method for the first time as our essential criteria to classify the site responses. Meanwhile the microtremors studies were not consistent with the strong motion results in our studies in Iran, which might be justified with the dry-arid climate mountainous conditions in most part of Iran; in any case the further microtremor tests should be performed. Similar studies might also be conducted in the neighboring countries of Iran; such as Turkey, Pakistan, Afghanistan Iraq, Caucasus and central Asian republics to develop and extrapolate the hazard mitigation results for this seismogenic region. In Iran, future developments of the strong motion network should favor the installation of instruments pairs; one on rock outcrop and another on nearby soil. This will provide the possibility to compare the H/V results with classical site to reference ratio. Other developments may be proposed in the form of "local arrays" for site studies in regions with high seismicity rate, and an important industrial and urban situation. We propose the first array of these series around the important city of Shiraz in southern Iran, where there is a high seismic activity, while a great part of the east of this city is located on soft soils and the underground water level is very high. Another local array with first priority of importance may be proposed for the city of Rasht on the shorelines of the Caspian sea in

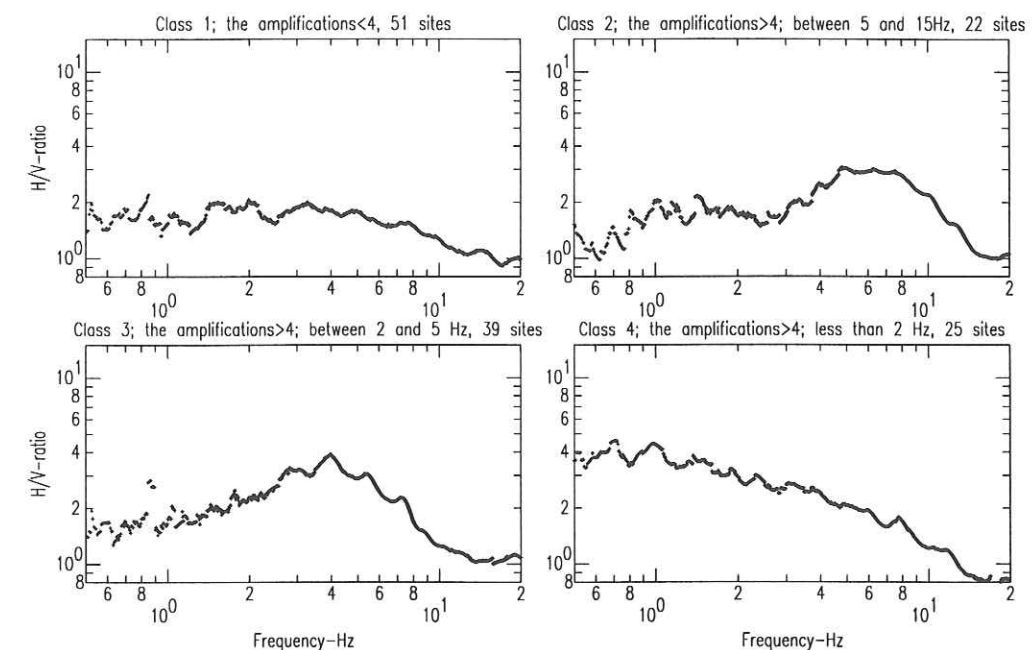


FIG. 3.26 – Average spectra for 4 site classes (using the RF SMS of all 138 sites).

northern Iran (near the epicenter of the Manjil earthquake of 1990; Mw7.3).

Acknowledgement

In this study many individuals have assisted us; most notably Messrs. Shirazian, Azadmanesh, Akbari and Mohseni (in IIEES) who assisted this project in the field studies, and Mirzaei-Alavijeh, Mahmoudi and Jalali in BHRC (Building and Housing Research Center, Tehran) who have completed the geoelectric tests. The financial support in Iran was provided by IIEES, and in France (for the first author) was provided by a French scholarship (Ministère Français des Affaires Etrangères), which are both duly acknowledged. The first author wants to thank F. Zoueshtiagh who has given some suggestions for article layout. Our thanks also go to Douglas McLean who has proof-read this text and has given comments to correct the orthography.

20 AOUT 2003
Univ. J. Fourier - O.S.U.G.
MAISON DES GEOSCIENCES
DOCUMENTATION
B.P. 53
F. 38041 GRENOBLE CEDEX
Tél. 04 76 63 54 27 - Fax 04 76 51 40 58
Mail: platour@ujf-grenoble.fr

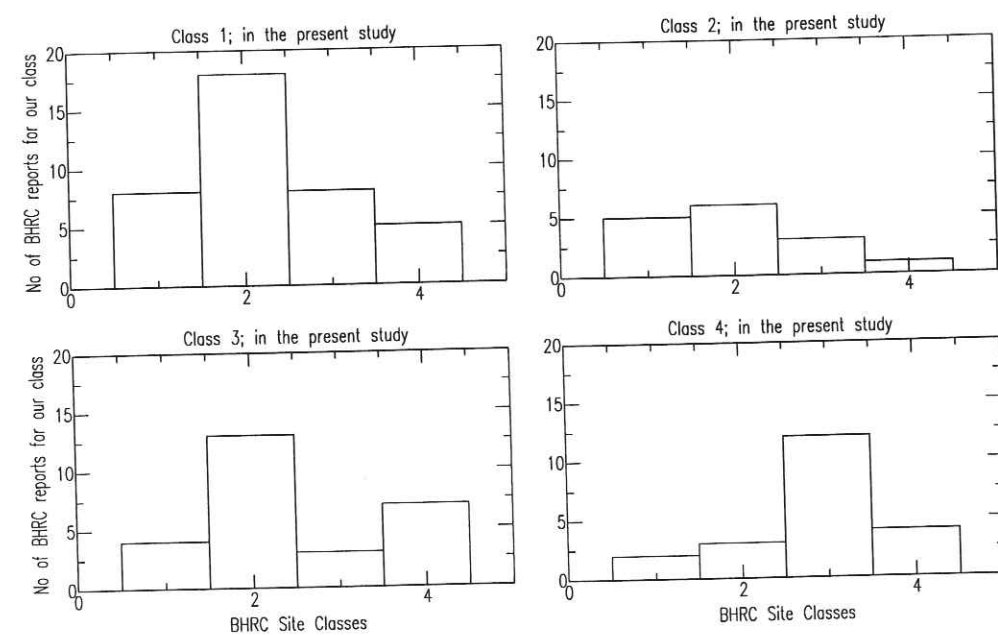


FIG. 3.27 – The comparison of the site classification in this study and that of BHRC (1993); The BHRC site classes are compared to each of the four classes defined in the present study.

Chapitre 4

Études particulières: la source sismique et Kappa

Résumé Les enregistrements accélérométriques ont permis l'étude du moment sismique en Iran. Les fréquences-coins des spectres de Fourier et les plateaux des spectres sont mesurés pour un ensemble de 468 enregistrements (de 360 événements), même si les paramètres des sources étaient a priori connus (enregistrements téléseismiques) pour seulement 190 événements. D'autres paramètres de la source sismique comme la fréquence maximale (f_{max}), et la chute de contrainte sont calculés et discutés aussi dans ce chapitre. Le moment sismique est utilisé pour déterminer la magnitude de moment, utilisé dans la suite des études sur les mouvements forts. Les valeurs de M_w sont proches de M_s pour les magnitudes supérieures à 6.0, et de mb , pour les magnitudes inférieures à 6.0. Les ML rapportés par les centres sismologiques iraniens sont plus dispersés mais sont cependant en accord avec les M_w , surtout pour les magnitudes inférieures à 6.0.

La chute de contrainte pour les séismes en Iran est représentative des régions intra-plaque. Ces valeurs sont entre 30 et 500 bars pour la plupart des séismes. D'autre part l'étude de la dépendance de f_{max} en fonction de la distance et la magnitude, montre une sensibilité presque similaire avec la magnitude et la distance, avec cependant un coefficient de corrélation sont un peu plus élevé pour la dépendance avec la magnitude. La dépendance des fréquences-coins en fonction de la magnitude et la distance est aussi étudiée, et on trouve une très bonne corrélation/négative avec la magnitude.

4.1 Seismic Moment and Stress Drop for the Strong Motion Accelerograms in Iran

Mehdi Zaré, Pierre-Yves Bard and Mohsen Ghafory-Ashtiany

Article en préparation

Abstract The moment magnitude (M_w) for the events recorded by the Iranian strong motion network is derived from the corner frequencies and spectral levels measured in the Fourier spectra of the corrected accelerograms. The calculation is done over a data-set of 468 three components time-histories (from 379 events), out of which the teleseismic source data were available for only 190 events. The hypocentral distances are also estimated based on the difference in the arrival times of compressional and shear waves. The comparison of the calculated moment magnitude and the reported teleseismic M_s , mb and M_w , and local ML values indicates that the calculated M_w 's are consistent with the teleseismic M_w 's; a good approximation is $M_w = M_s$

for the magnitudes over 6, and $M_w = mb$ for magnitudes below 6. The ML values inferred by local seismological networks in Iran (corresponding to magnitudes below 6) exhibit a larger scatter with, however, an average satisfactory agreement. The magnitudes for moderate events (mostly in southern Iran, Zagros region, for which no report existed on their source) are thus estimated by this method. In addition, the estimated stress drops for this data-set (between 30 and 500 bar) correspond better to intra-plate earthquake.

4.1.1 Introduction

The purpose of this study is to determine the magnitude of the earthquakes recorded in the Iranian network, for which no teleseismic or local information exists on their localisation and magnitude. The moment magnitude is thus derived from the Iranian strong motion data (corresponding to earthquakes occurred between 1975 and February 1997). The strong motion data in this study were recorded by two types of instruments: the analog SMA-1 instruments have been installed in Iran since 1975, but have been steadily replaced by the digital SSA-2 instruments after the Manjil earthquake of 1990 ($M_w 7.3$). Some 468 three component accelerograms, out of 750 uncorrected records, are selected and filtered. The investigated data set comprises 169 analog and 299 digital records: out of which the source parameters were available only for 279 records (169 analog and 110 digital; Bard et al 1998). Since it was essential to use as much data as possible to establish the attenuation laws for Iran, and the application of a uniform magnitude scale was necessary, the moment magnitudes are calculated.

The earthquake magnitudes in Iran are reported by the international bodies for larger events (PDE monthly reports and ISC bulletins), as well as the local seismologic centers (Institute of Geophysics, Tehran University, IGTU).

In this paper, after a brief outline of method used to calculate the seismic moment, it is applied to the Iranian records for which no teleseismic source data could be found, and the results are presented in a Table (Appendix 4.1). The correlation of the estimated M_w with the other magnitude scales is indicated. Then, the causes for discrepancies from the ideal model are described. The stress drop estimations are presented as well.

4.1.2 Methodology of the Study: the $\omega^{-\gamma}$ model

Haskell (1964) has already proposed a simple source model for the estimation of high frequency ground motions. The simple seismic source models are explained by Aki (1967), and Brune (1970; 1971). In this model, the far field displacement spectrum is characterized by a flat

level Ω proportional to M_0 at long periods, a corner frequency f_c proportional to inverse of the source dimension, and a high frequency spectral decay in the form $(\frac{f}{f_c})^{-\gamma}$. Taking the γ values as 2 or 3, we have the ω -square or ω -cube model, respectively (ω is the angular frequency in radians per second, equal to $2\pi f$). Hanks (1982) has shown that with a ω -square model, for which the acceleration spectra would be flat after the corner frequency, f_c , the high frequency decay may in the acceleration spectrum be explained by the attenuation along the wave path. As proposed by Hanks (1979), the displacement spectra may be represented by;

$$\Omega = \frac{\overline{\Omega}_0}{1 + (\frac{f}{f_c})^\gamma}$$

where $\overline{\Omega}_0$ is the value of the low frequency flat part of the displacement spectrum. For far-field S-waves due to a double couple source embedded in an elastic, homogeneous, isotropic half-space, we have:

$$\overline{\Omega}_0 = \frac{1}{4\pi R_h} \cdot \frac{M_0}{\rho} \cdot \frac{1}{\beta^3} \cdot (R'_{\theta\phi}) \cdot F_s$$

where β is the shear wave velocity of the medium, ρ its density; (around 2.8×10^3 kg/m³), R_h the hypocentral distance, $R'_{\theta\phi}$ the double couple radiation pattern for SH or SV waves (about 0.6 in average), F_s is the free surface amplification factor (to be taken equal to 2).

The value of the flat part of the acceleration spectrum, A_0 , may be related to $\overline{\Omega}_0$ with

$$A_0 = \overline{\Omega}_0 \cdot \omega_c^2$$

Hence, M_0 could be written as

$$M_0 = \left(\frac{A_0}{(2\pi f_c)^2} \right) \cdot \frac{4\pi R_h \cdot \rho \cdot \beta^3}{R'_{\theta\phi} \cdot F_s} \quad (4.1)$$

In the following, β is taken equal to 3×10^3 m/sec, and $\rho = 2.8 \times 10^3$ kg/m³.

Kanamori (1977) has defined a new magnitude scale based on the seismic moment, that is more reliable measure of the size of the great earthquakes. This scale is defined as:

$$M_w = 0.667 \times \log M_0 - 6.0 \quad (4.2)$$

We used the formula 4.1 and 4.2 to calculate M_w for the events recorded in Iranian strong motion network.

The static stress drop is related to the moment magnitude and source radius (Kanamori and Anderson 1975). The source radius might be estimated using the Brune model (1970) by:

$$r_0 = \frac{2.34}{2\pi} \cdot \frac{\beta}{f_c} \quad (4.3)$$

r_0 is the source radius in meter. For circular faults, the stress drop is related to r_0 with:

$$\Delta\sigma = \frac{7}{16} \cdot \frac{M_0}{r_0^3} \quad (4.4)$$

where $\Delta\sigma$ is the stress drop, in Pascal ($1Pa = 10^{-5}$ bar).

4.1.3 The sources of Uncertainties

Some essential causes for uncertainties or errors may be classified as follows:

- The pre-event memory does not exist in analog data. Therefore, the determination of the first arrival of P waves, and then the hypocentral distances were difficult for such data in Iran. This difficulty does not exist, fortunately, for most of the digital records.
- The handy digitalization of the SMA-1 records made a lot of problems to pick a corner frequency the f_c and A_0 .
- In digital records of moderate magnitude events $M < 4$, the spectral amplitudes are very low. Therefore, it was sometimes difficult to distinguish the signals from the noises coming from the sensor. The cases with high noise level are eliminated.
- In very high amplitude records of high earthquakes ($M > 7.0$ distances below 50km), the interferences of different waves make it impossible to identify P and S waves. Therefore, this method of calculation of M_w , is to be used with caution for such records. The fault distance should be obtained by other means (aftershock studies, for instance).

4.1.4 Results

To establish the Iranian strong motion catalogue, some 169 records were selected from a total of 430 three component analog accelerograms (Bard et al 1998a). The first arrival of the P waves was not always clear, therefore it was difficult to calculate the hypocentral distance, R_h using the difference of S and P arrivals;

$$R_h = 8 \times (t_s - t_p) \quad (4.5)$$

The digital records, which are the main purpose of this article, present more suitable conditions; for 110 digital records the source parameters, were available from teleseismic studies (ISC, NEIC), while for 192 others there were not. A pre-event memory at the beginning of almost all of the SSA-2 records permitted the observation of t_p and t_s more easily. On the other hand, the satisfactory quality of digital records provides the opportunity for more precise measurement of the corner frequencies and the flat part of the acceleration spectra.

An example from a digital record

A digital (SSA-2) three component accelerogram that is obtained in Hosseinieh village (southern Iran; Figure 4.1) is shown in Figure 4.2. This record was obtained during an earthquake on 31 July 1994, with reported source parameters of $M_s=5.3$, $m_b=5.3$, $M_w=5.6$, a focal depth of 43 km according to NEIC, and $ML_{4.5}$ (IGTU). Regarding the epicenter coordinates for this event, the epicentral distance for the record would be found as 20 km, and the hypocentral distance at 45km. A closer zoom on the first 6 seconds of the record is indicated in Figure 4.3. The first arrivals for P and S waves, t_p and t_s , are estimated at 1.5 ± 0.3 and 4.7 ± 0.3 , respectively, therefore R_h equals $25.6 \text{ km} \pm 5 \text{ km}$. Taking to account highest peaks of the amplitude spectra, A_0 equals $0.35 \text{ m/sec} \pm 0.15$ (Figure 4.4), and f_c is measured at $1.2 \pm 0.3 \text{ Hz}$. The seismic moment is therefore, $M_0 = 3.9 \times 10^{17} \text{ N-m}$. With 4.2, we have $M_w=5.5 \pm 0.3$.

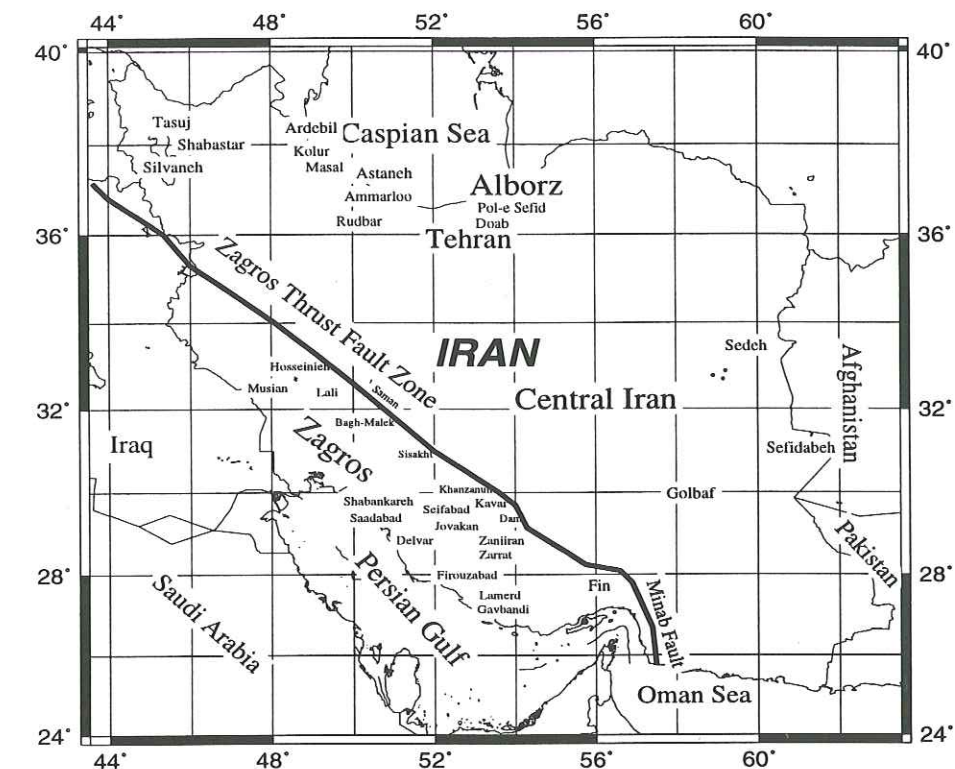


FIG. 4.1 - The locations of the studied selected accelerometric sites in Iran in this paper.

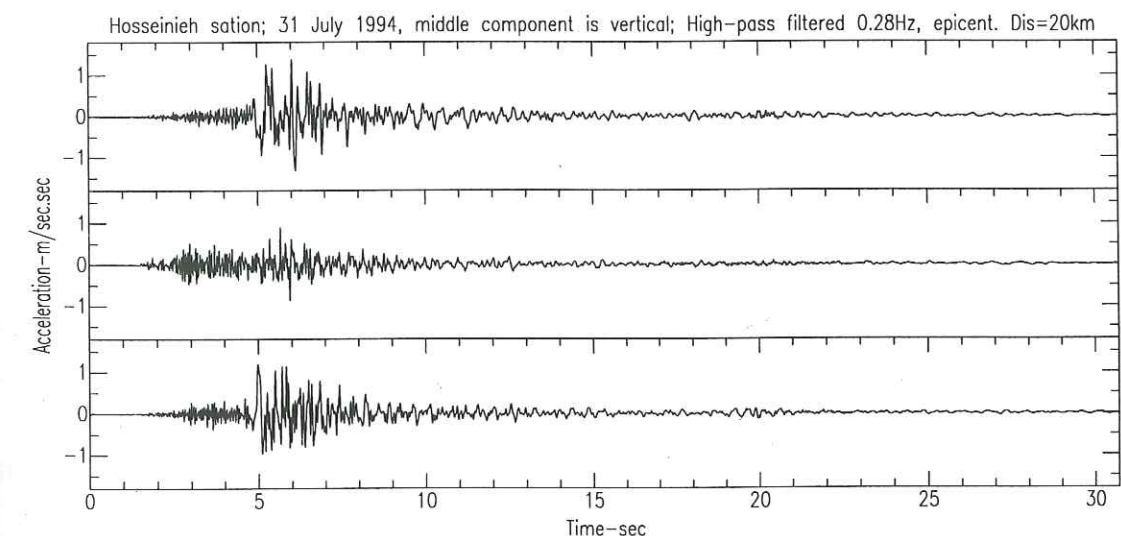


FIG. 4.2 - Hossienieh record of the event of 31 July 1994.

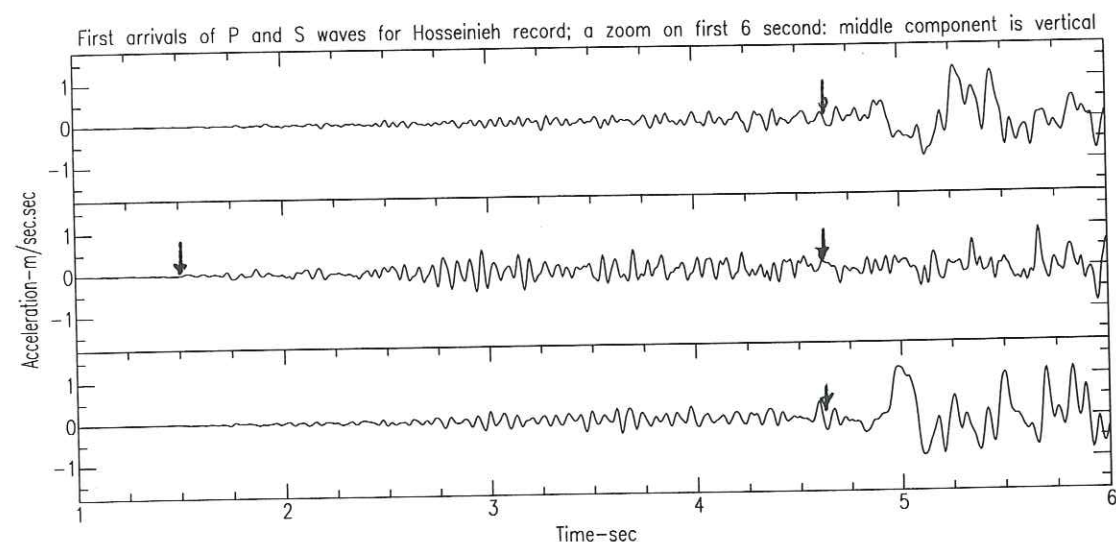


FIG. 4.3 – A zoom on the first 6 seconds of the record in Fig. 4.2; the first arrow at 1.5 seconds for t_p and the second on at 4.7 seconds for t_s .

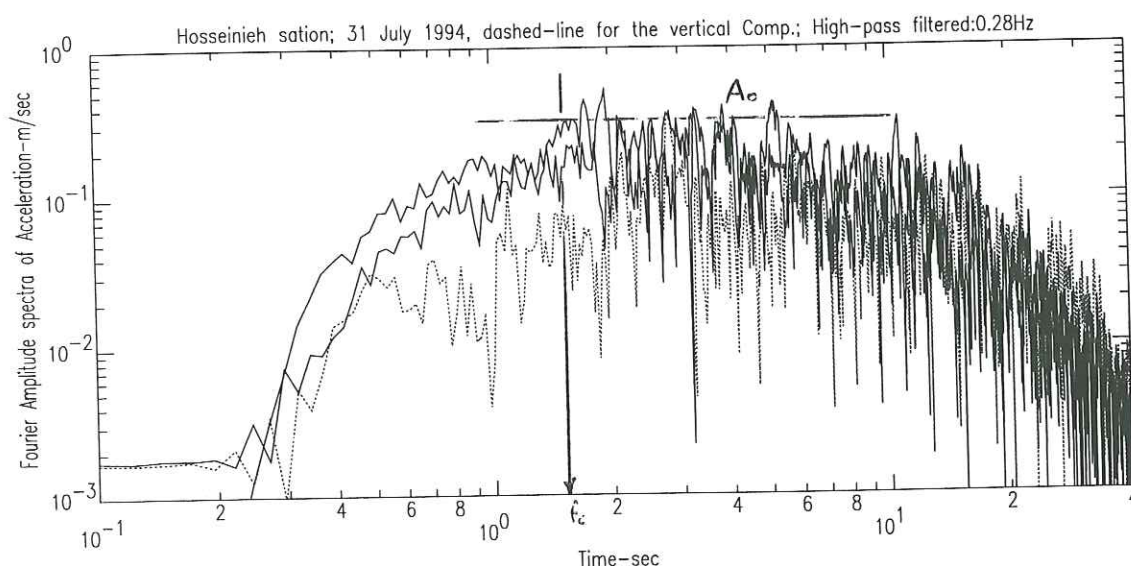


FIG. 4.4 – The Fourier Amplitude Spectra of Acceleration of Hosseinieh record.

4.1.5 Application of the method for the records with no reported source

The recent digital accelerometric data in Iran, recorded after January 1994, contains a lot of records with only the triggering time. To use these data in the attenuation studies, the moment magnitudes and the hypocentral distance are calculated according to the method outlined in the previous section. The results are displayed in Appendix 4.1, listing for each record the BHRC code, the station name, the site class (based on the site classes 1 to 4, already defined by Zaré et al 1999a), the date (as mentioned in the header of the record), the high-pass filter used to avoid the low-frequency noise, the horizontal and the vertical peak ground accelerations (HPGA and VPGA, respectively), the corner frequency, the stress drop in bar, the hypocentral distance and finally the calculated moment magnitude (M_w). Most data presented in Appendix 4.1 were recorded in Zagros region, however a few data come from western Alborz in Caspian Sea shoreline, Azarbaijan in NW, as well as some records from eastern Iran (Figure 4.1).

For 27 events, several stations triggered, allowing an investigation on the stability and reliability of this M_w determination. The results are displayed in Figure 4.5, with stability for the f_c and stress drop calculation for the same 27 events. This figure exhibits an average standard deviation on moment magnitude of 0.19, corresponding to a factor of $10^{\frac{0.19}{0.667}} = 10^{0.28} \approx 3$ on seismic moment. The average standard deviations for $\log f_c$ and stress drop are 0.47 and 8.93, respectively.

Comparison of the calculated M_w with reported teleseismic magnitudes

The calculated M_w 's are plotted against the teleseismic reported M_s 's, m_b 's, and M_w 's and M_L 's, in Figure 4.6. It is evident that;

- The calculated M_w 's are consistent with reported teleseismic M_w 's.
- For magnitudes over 6, the calculated M_w are in agreement with M_s values, but for magnitudes below 6, they coincide more with the m_b values (m_b values saturate in magnitudes around 6-6.0; Figure 4.7).
- The local magnitudes inferred from the local seismological network in Iran are more scattered but agree however with the calculated M_w values. These values correspond to magnitudes below 6.

Stress Drop estimation

The stress drop is estimated using formula 4.4 and presented in Appendix 4.1. The stress drop depends to the corner frequency, f_c (4.3 and 4.4). The observed f_c 's for Alborz-Central

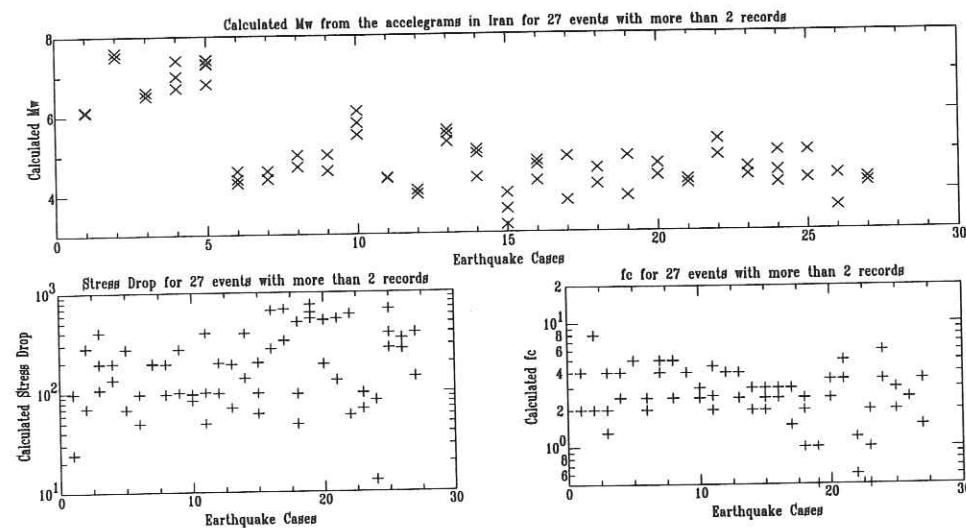


FIG. 4.5 – The stability of the M_w 's calculated in this study, for 27 cases and f_c and stress drop for 13 events with more than 2 records.

Iran and Zagros are plotted in Figure 4.8 against M_w . They are between 1 and 10 Hz for most of the records. No important difference may be seen between these two regions on this limited data-set. The stress drop values are then obtained and traced against f_c in Figure 4.9 and against M_w in Figure 4.10. The estimations of the stress drops in Iran are mostly between 30 and 500 bars (3 to 50 MPa). According to Kanamori and Anderson (1975) and Kanamori (1977), they are thus representative for the intra-plate earthquakes.

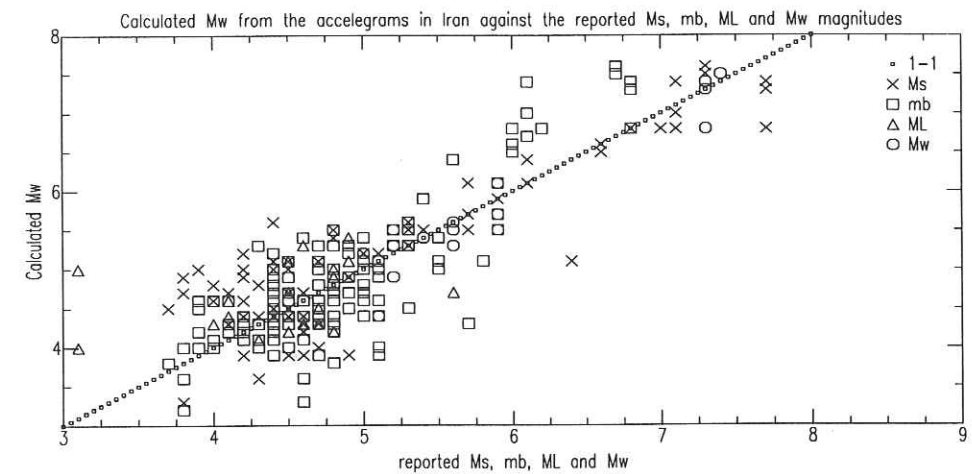


FIG. 4.6 – Comparison between calculated M_w and the teleseismic and local magnitudes.

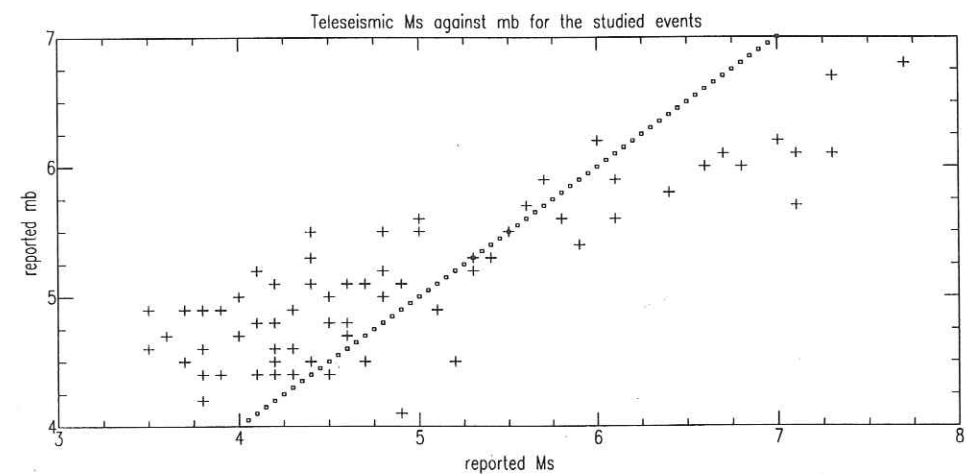


FIG. 4.7 – Comparison between M_s and m_b values

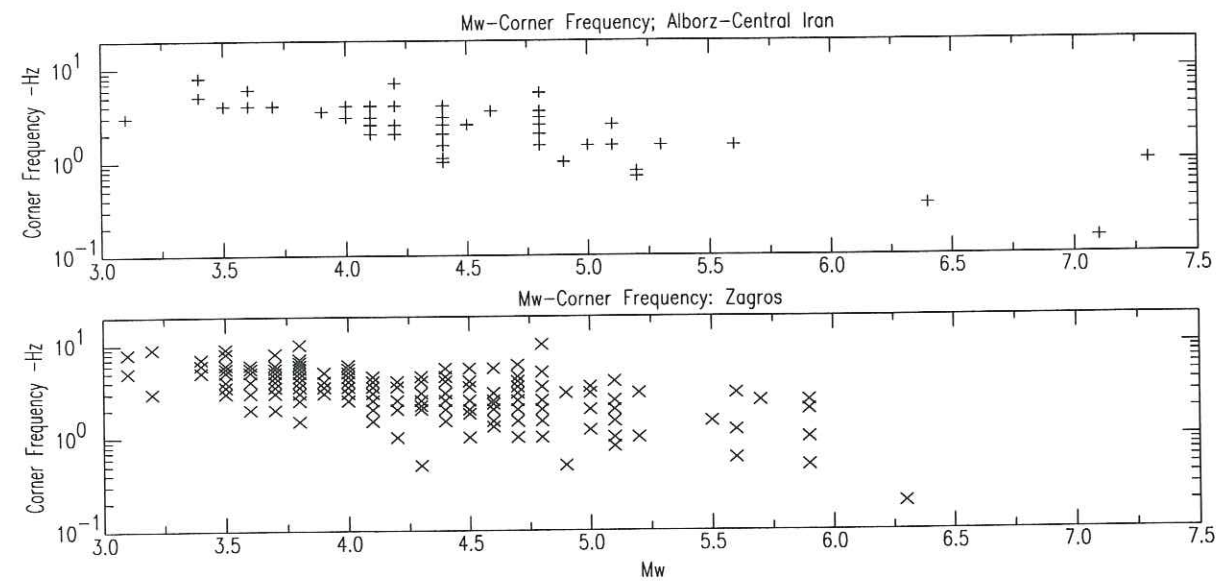


FIG. 4.8 - The observed corner frequencies against M_w for Alborz-Central Iran and Zagros regions.

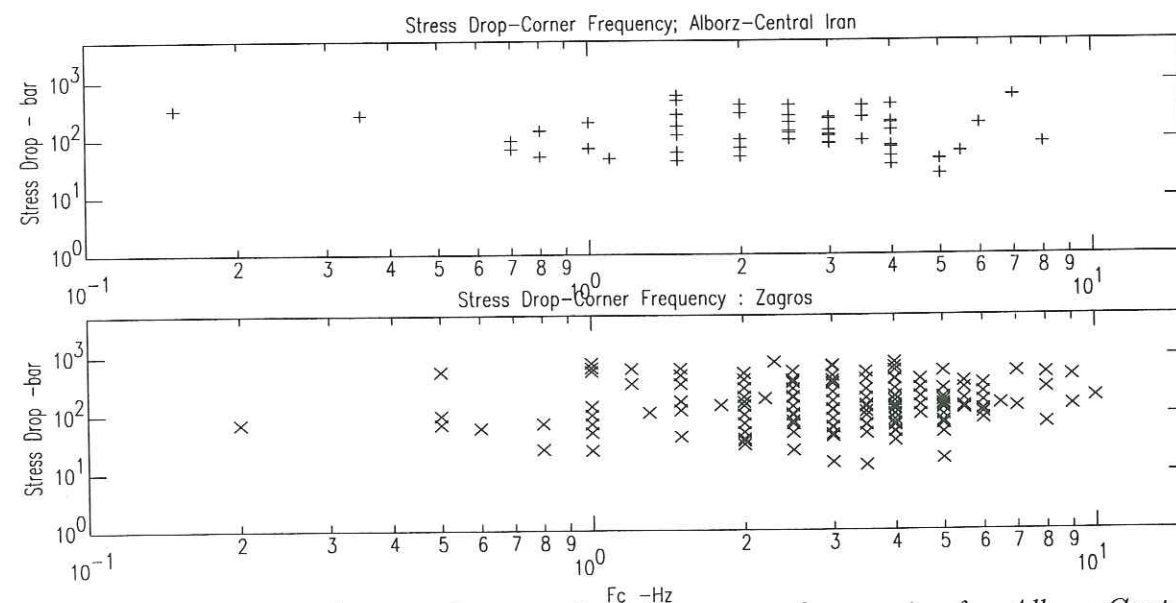


FIG. 4.9 - The estimated stress drops against the corner frequencies for Alborz-Central Iran and Zagros regions.

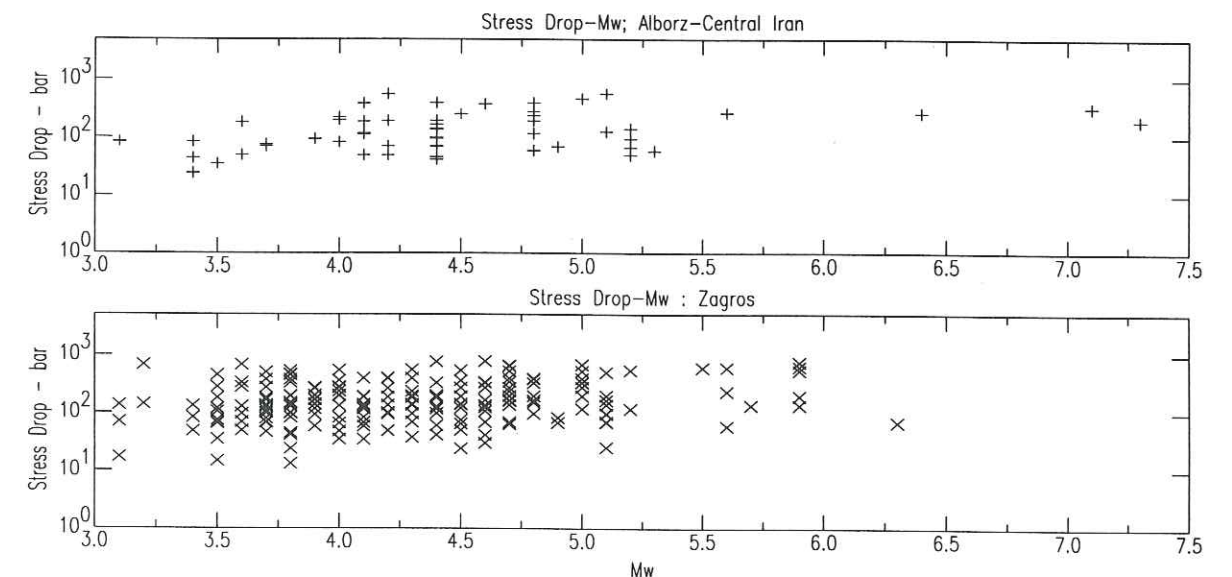


FIG. 4.10 - The estimated stress drops against M_w for Alborz- Central Iran and Zagros regions.

Dependence of f_c and f_{max} to magnitude and distance

The dependence of f_c and f_{max} to magnitude and distance is investigated, with the two following relationships:

$$\log f = a \cdot M + c + \sigma_1 \cdot P \quad (4.6)$$

$$\log f = -b \cdot \log R_h + d + \sigma_2 \cdot P \quad (4.7)$$

where a and b are the coefficients of M_w and R_h , respectively, c and d are constants and σ_1 and σ_2 are standard deviation and P percentile. The obtained coefficients are given in Table 4.1 for f_c and in Table 4.2 for f_{max} . The correlation coefficient (R) for f_c show that f_c depends completely to M_w where no correlation is evident between f_c and hypocentral distance. The dependence of f_{max} to M_w and hypocentral distance is similar (with a slightly higher R for the dependence on M_w).

Table 4.1: The coefficients for relationships 4.6 and 4.7, for f_c .

a	c	σ_1	R
-.345	1.940	0.151	0.579
b	d	σ_2	R
0.295	0.825	0.253	0.001

Table 4.2: The coefficients for relationships 4.6 and 4.7, for f_{max} , for horizontal and vertical components.

Comp.	a	c	σ_1	R
Hori.	-.185	1.781	0.162	0.468
Vert.	-.130	1.785	0.145	0.469
	b	d	σ_2	R
Hori.	0.386	1.623	0.167	0.398
Vert.	0.341	1.647	0.148	0.400

4.1.6 Conclusions

The moment magnitudes calculated from the Iranian strong motion data provide satisfactory results: The calculated values are consistent with teleseismic estimates of M_w , while they agree with M_s for magnitudes larger than 6, and with m_b for magnitudes below 6. It becomes therefore possible to use the records from events within low to medium magnitude range (M3-5) in the attenuation studies, even though there does not exist any teleseismic or local report. These data in Iran were recently made available using the new digital SSA-2 network. Of course, it would be better to have an improved seismological network in Iran, so as to locate precisely and have more reliable magnitude determinations. On the other hand, it is suggested to improve the maintenance of the accelerometric network in Iran, so as to systematically assign source characteristics to each strong motion record. In particular the use of a GPS system is recommended to obtain an absolute timing for all the instruments in this network. The present situations, without precise timing, greatly impairs detailed source studies, which is really a pity with so many instruments installed in such an active seismic area.

Acknowledgement

The BHRC (Building and Housing Research Center, Tehran) who have released the raw strong motion records is greatly thanked. A financial support in France (for the first author) provided by a French scholarship (Ministère Français des Affaires Etrangères) is duly acknowledged. Douglas Maclean is greatly acknowledged for controlling the orthography of this article.

4.2 Décroissance de l'amplitude à haute fréquence dans le spectre de Fourier de l'Accélération: coefficient Kappa

Résumé La décroissance à haute fréquence du spectre de Fourier de l'accélération est étudiée sur les données iraniennes, pour détecter d'éventuelles non-linéarités dans les sols peu rigides. Cette décroissance est caractérisée par le paramètre Kappa (Anderson et Hough 1984), dont la valeur a été estimée seulement pour les données ayant un bon rapport signal sur bruit à haute fréquence. Lorsque κ pouvait être mesuré sur un même site, pour plusieurs enregistrements présentant différents niveaux d'accélération, nous avons étudié les variations de κ avec cette accélération. Nous avons d'autre part repris la classification par site et étudié les variations statistiques de κ (tous les sites d'une même catégorie mélangés) avec le niveau d'accélération, de même que les variations de κ avec le type de site. Les résultats de ces analyses restent très flous: κ semble cependant affecté légèrement quand la rigidité du site diminue, indiquant que κ serait au moins partiellement lié à l'atténuation de proche-surface.

4.2.1 Introduction

La décroissance haute fréquence des spectres de Fourier de l'accélération $A(f)$ est souvent caractérisée par un paramètre appelé κ , correspondant à une décroissance en $e^{-\kappa f}$. Deux interprétations existent, liant cette décroissance à l'atténuation de la croûte et du sol (Anderson et Hough 1984, Durward et al. 1996, Hanks 1982, Lacave-Lachet et al. 1998) ou à la source (Papageorgiou and Aki 1983, Gariel et Campillo 1989). Hanks (1982) suppose que la fréquence maximale (f_{max}) est induite par l'atténuation anélastique propose dans une relation entre κ et la distance à la source. Lachet-Lacave et al (1998) reprennent cette interprétation pour détecter des non-linéarités dans les enregistrements obtenus lors de la séquence du séisme de Kobé (1995) au Japon; les sols mous soumis à de fortes accélération devraient en effet voir leur amortissement augmenter, et donc κ augmenter. A l'opposé, Papageorgiou et Aki (1983) ont montré que la décroissance en haute fréquence serait liée à l'existence d'une zone de collision (non-élasticité de la faille) à l'avant du front de la rupture, dont la taille contrôlerait la fréquence f_{max} . Gariel et Campillo (1989), en utilisant une approche numérique, ont confirmé que deux facteurs liés à la source peuvent expliquer la décroissance haute fréquence: la présence de cette 'zone de cohésion', mais aussi le ralentissement lissé du front de rupture.

La méthodologie des études sur κ est présentée d'abord. Les relations de κ avec la distance

sont ensuite étudiées pour les différentes régions de l'Iran.

4.2.2 La méthodologie des calculs de Kappa

La partie haute fréquence d'un spectre d'accélération peut être représentée comme suite:

$$A(f) = A_1 e^{-\pi \kappa f} \text{ pour } f > f_{max}$$

où $A(f)$ est le spectre de l'accélération, et A_1 est une constante qui dépend des propriétés de la source, de la distance épacentrale et peut-être d'autres facteurs, f est la fréquence, κ est le coefficient de décroissance, et f_{max} est une fréquence au-dessus laquelle la forme spectrale ne peut pas être distinguée de la décroissance exponentielle. En supposant un milieu simple sur un demi-espace élastique, on peut écrire:

$$\kappa = \int \frac{ds}{Q\beta}$$

où ds est l'élément de rayon sismique, Q est le facteur de qualité, et β est la vitesse des ondes S.

Cette intégrale peut se décomposer en 2 termes: l'un correspondant à la propagation dans les milieux très superficiels à proximité de la station d'enregistrement et l'autre à la propagation dans la croûte profonde:

$$\kappa = \frac{l_c}{Q(f) \cdot \beta_c} + \frac{h_s}{Q_s \cdot \beta_s}$$

où l_c est la distance totale parcourue dans la croûte, caractérisée par un facteur de qualité $Q_c(f)$ et une vitesse d'onde S, β_c ; h_s est l'épaisseur des milieux superficiels, Q_s leur facteur de qualité, et β_s leur vitesse d'onde de cisaillement. Selon cette décomposition, le premier terme va produire un coefficient κ qui va augmenter avec la distance source-site (l_c), tandis que le second sera sensible aux effets non-linéaires, puisque en un site donné, Q_s devrait diminuer, et β_s aussi, quand l'accélération augmente beaucoup.

4.2.3 Les résultats

Les valeurs de κ ainsi calculées sont représentées en fonction de la distance pour les régions de Zagros, et Alborz-Iran Central et pour 4 catégories des sites différents dans les Figures 4.11 à 4.13, respectivement. Les résultats du Zagros sont très dispersés, et ne correspondent qu'à de faibles distances (la plupart avec $R_h < 20\text{km}$). Ces données viennent des enregistrements plutôt digitaux obtenus pour des séismes de magnitude inférieure à 6 (Figure 4.11). Les résultats en Alborz-Iran Central (pour les séismes des magnitudes de moins de 6, pour comparer avec les données du Zagros, Figure 4.12) montrent des variations moins rapides avec la distance (Figures 4.12 et 4.13). Pour mieux expliquer les valeurs de kappa en champ-proche, il y aurait besoin d'études supplémentaires.

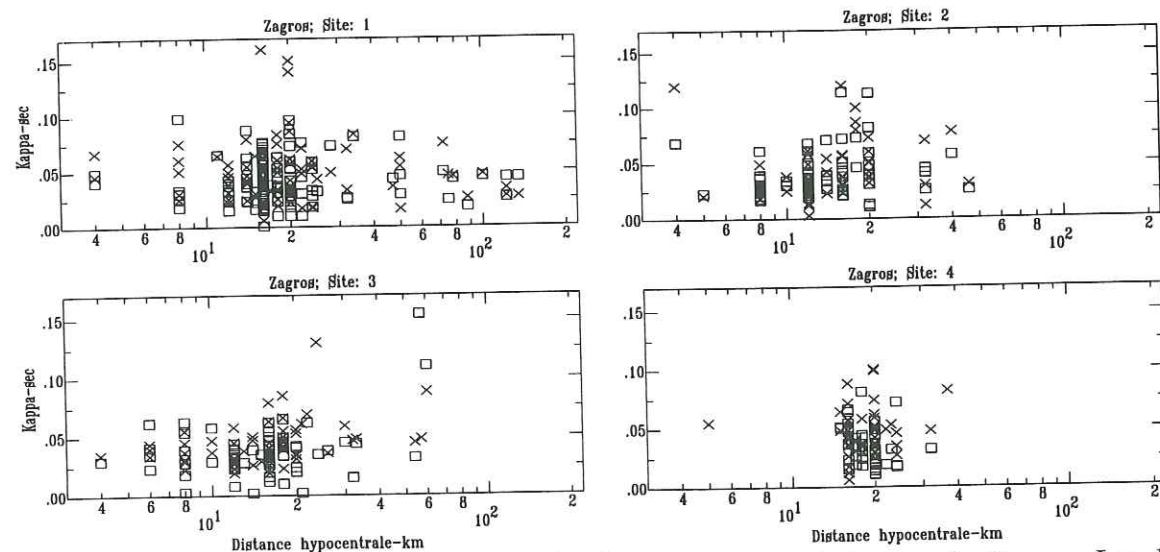


FIG. 4.11 – Les valeurs de κ en fonction de la distance hypocentrale pour le Zagros. Les données sont présentées pour différentes catégories de site. Les croix correspondent aux composantes horizontales et les rectengules aux composantes verticales.

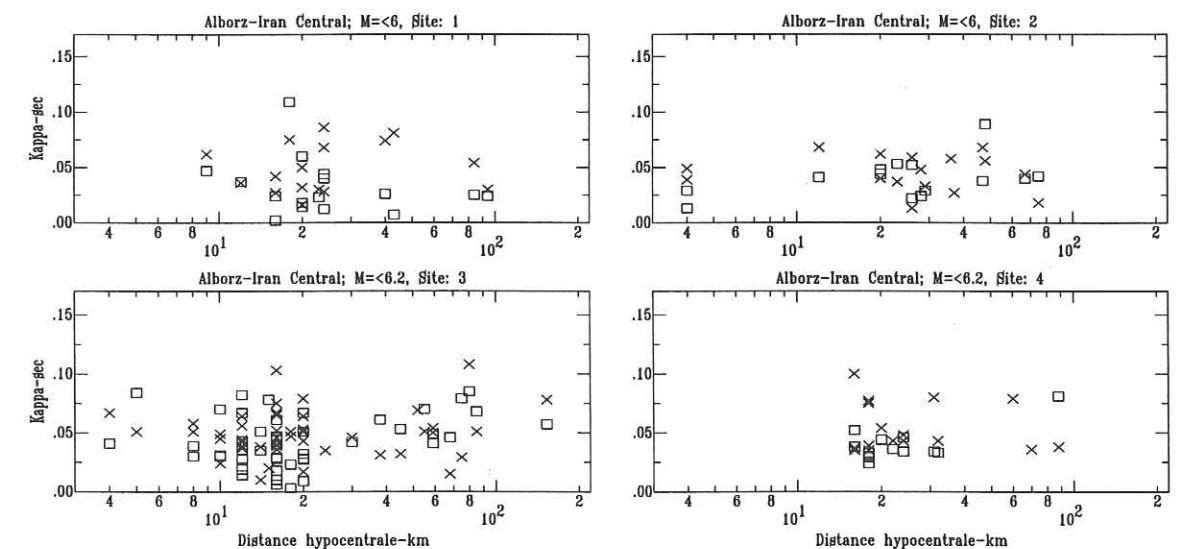


FIG. 4.12 – Les valeurs de κ en fonction de la distance hypocentrale pour l'Alborz-Iran Central; les événements de magnitudes moins de 6. Les données sont présentées pour les catégories différentes de site. Les croix correspondent aux composantes horizontales et les rectengules aux composantes verticales.

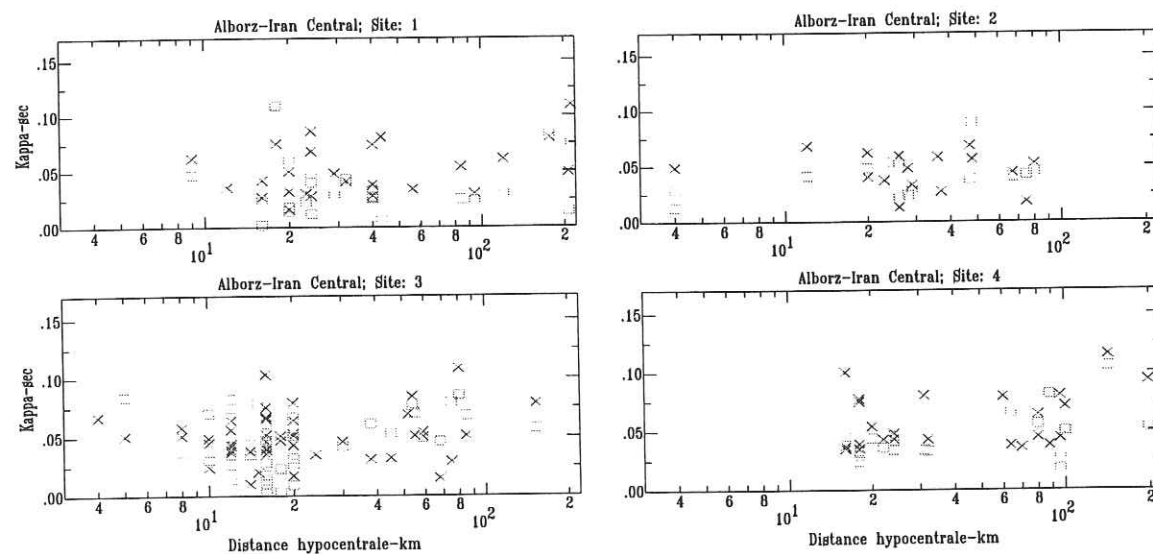


FIG. 4.13 – Les valeurs de κ en fonction de la distance hypocentrale pour la région de l'Alborz-Iran Central (sans limitation de la magnitude). Les données ont été présentées pour les catégories différentes de site. Les croix correspondent aux composantes horizontales et les rectangles aux composantes verticales.

Pour en être sûr, nous avons considéré quelques séismes particuliers pour lesquels nous disposons de plusieurs enregistrements (Ebrahimabad, etc.). La Figure 4.14 pourrait montrer une légère augmentation de κ avec la distance, notamment pour le séisme de Manjil, mais les valeurs varient beaucoup d'un séisme à l'autre, de telle sorte qu'il est impossible de distinguer une dépendance de κ avec la distance pour séismes correspondants. Par ailleurs, les valeurs de κ ont été présentées en fonction de l'accélération maximale pour les sites avec plusieurs enregistrements en Figure 4.15. Ces résultats montrent la variation de κ plus ou moins similaires pour les types différents de sol, et aucune tendance à l'implification de κ avec l'accélération maximale.

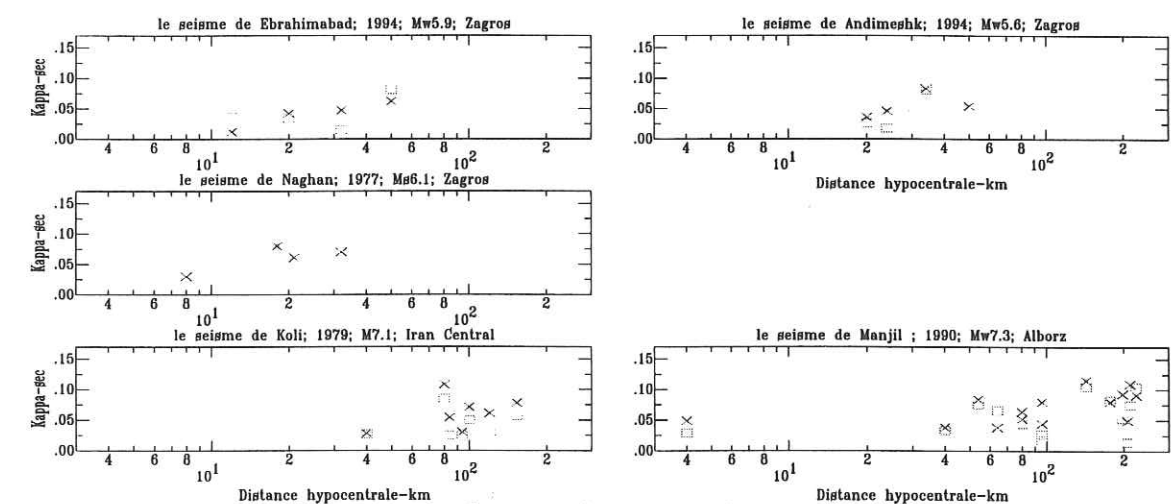


FIG. 4.14 – Variation de κ avec la distance hypocentrale pour les séismes avec les magnitudes supérieures à de 5.9 pour les régions de Zagros, Alborz-Iran Central [Ebrahimabad 1994, Andimeshk, 1994, et Naghan 1977 dans la région de Zagros, et Koli 1979 en Iran Central et Manjil 1990 en Alborz]. Les croix correspondent aux composantes horizontales, et les rectangles aux composantes verticales.

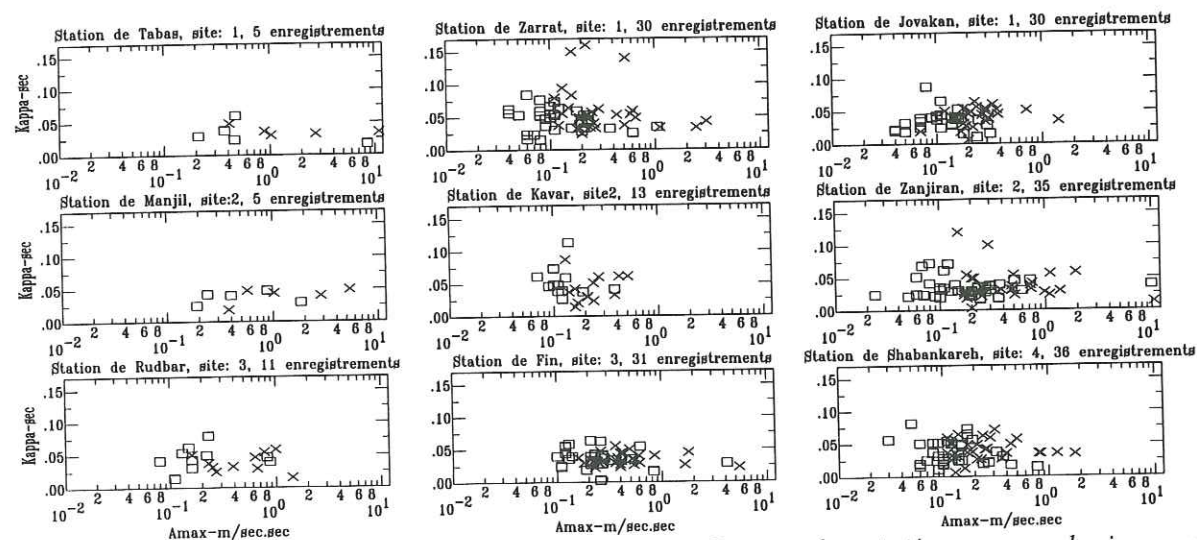


FIG. 4.15 - Variation de κ avec l'accélération maximale pour les stations avec plusieurs enregistrements: Tabas, Zarrat, Jovakan (site 1), Manjil, Kavar et Zanjiran (site 2), Rudbar et Fin (site 3) et Shabankareh (site 4). Les croix correspondent aux composantes horizontales et les rectangles aux composantes verticales.

Ces résultats au κ suggèrent une très faible influence des conditions de site dans les données iraniennes. Concernant un autre faible dépendance avec la distance, nous en concluons que probablement la théorie de Papageorgiou et Aki, et Gariel et Campillo (1989), selon laquelle les effets de source sont prédominants sur le comportement haute fréquence, est plus en accord avec ces résultats actuels.

4.2.4 Conclusion

Les études sur le paramètre de κ en Iran montrent essentiellement une très forte dispersion, surtout dans les premiers 20km (surtout dans les données de Zagros) à telle point qu'il est impossible de détecter une tendance. Pour aller plus loin, il faudrait disposer de données de réseaux accélérométriques locaux avec plus des stations numériques, en comparant les données des chocs principaux et des répliques enregistrés sur les sites différents et par des distances différentes. Nous proposons l'observation de la forme de spectre de l'accélération en haute fréquence surtout pour le champ-proche des sources sismiques les plus importantes les plus connues en Iran. Ce type des études particulières permettent de relier κ à l'atténuation superficielle ou profonde.

Appendix 4.1: The Iranian digital records (SSA-2 instruments) for which the source parameters are estimated directly for the records.

No	Code BHRC	Station	Site	Event	HP filter (Hz)	PGA (H1) m/sec ²	PGA (V) m/sec ²	PGA (H2) m/sec ²	f max (H) Hz	f max (V) Hz	fc (Hz)	Stress Drop (Bar)	Ao m/sec	Hypo Dist. (km)	Mw calc.
1	1512-1	Sedeh	3	07/07/94	0.44	.435	.650	.438			2.5	251.6	0.1	16	4.5
2	1505	Sefidabeh (Microwave)	1	1/3/94	0.20	.088	.093	.134	10.0	10.0	2	98.1	0.04	24	4.4
3	1504-1	Sefidabeh (School)	2	1/3/94	0.27	.068	.032	.052			4	24.15	0.006	16	3.4
4	1492-1	Zarrat	1	8/3/94	0.10	.420	.190	.258	12.0	15.0	4	393.5	0.09	16	4.2
5	1503-1	Zanjiran	2	9/3/94	0.24	.191	.105	.193	18.0	18.0	5	193.2	0.06	12	3.8
6	1503-2	Zanjiran	2	9/3/94	0.24	.258	.201	.115	25.0	30.0	8	280.9	0.055	12	3.5
7	1494-1	Kavar	2	11/3/94	0.25	.191	.230	.176	30.0	35.0	2	69.5	0.05	12	4.3
8	1500-1	Zanjiran	2	11/3/94	0.28	.216	.107	.138	10.0	10.0	8	280.9	0.08	8	3.5
9	1500-2	Zanjiran	2	13/3/94	0.25	.178	.104	.109	26.0	30.0	9	142.0	0.03	8	3.2
10	1500-3	Zanjiran	2	14/3/94	0.25	.095	.078	.166	28.0	30.0	4	555.8	0.25	8	4.3
11	1492-3	Zarrat	1	17/3/94	0.14	.728	.272	.613	20.0	25.0	2	195.7	0.10	16	4.6
12	1494-2	Kavar	2	17/3/94	0.25	.145	.080	.223	10.0	15.0	1.3	107.2	0.08	20	4.8
13	1494-3	Kavar	2	17/3/94	0.20	.242	.115	.211	15.0	15.0	2.5	382.3	0.20	12	4.6
14	1500-5	Zanjiran	2	17/3/94	0.23	1.111	.299	.730	18.0	22.0	4	402.6	0.10	16	4.2
15	1500-7	Zanjiran	2	18/3/94	0.25	.099	.061	.198	25.0	30.0	6	118.5	0.045	8	3.5
16	1500-9	Zanjiran	2	19/3/94	0.28	.119	.061	.177	25.0	30.0	5	136.8	0.04	12	3.1
17	1500-10	Zanjiran	2	20/3/94	0.20	.277	.141	.351	20.0	25.0	3	234.5	0.10	12	4.3
18	1500-11	Zanjiran	2	20/3/94	0.30	.153	.136	.182	20.0	25.0	3	83.2	0.035	12	4.0
19	1500-12	Zanjiran	2	21/3/94	0.30	.386	.154	.298	30.0	35.0	4.5	140.8	0.075	8	3.8
20	1492-10	Zarrat	1	12/4/94	0.44	.201	.062	.052	20.0	20.0	7	133.3	0.02	14	3.4
21	1492-12	Zarrat	1	7/5/94	0.25	.153	.066	.166	10.0	10.0	2.5	135.7	0.04	20	4.2
22	1502-1	Zanjiran	2	20/5/94	0.21	.149	.049	.144	15.0	20.0	3	117.5	0.045	16	4.1
23	1502-3	Zanjiran	2	5/6/94	0.21	.112	.081	.235	25.0	28.0	10	194.8	0.025	12	3.2
24	1502-5	Zanjiran	2	6/6/94	0.20	.377	.194	.716	20.0	28.0	4	393.5	0.15	10	4.2
25	1492-17	Zarrat	1	20/6/94	0.25	.214	.078	.227	18.0	18.0	2.2	184.5	0.10	16	4.5
26	1492-18	Zarrat	1	20/6/94	0.20	.090	.038	.129	11.0	15.0	4	197.3	0.045	16	4.0
27	1493-3	Firouzabad	3	20/6/94	0.20	.128	.078	.135	6.0	8.0	2.5	135.7	0.05	18	4.3
28	1492-21	Zarrat	1	21/6/94	0.24	.159	.095	.157	18.0	18.0	4.5	396.8	0.07	18	4.1
29	1518-1	Firouzabad	3	22/6/94	0.40	.359	.073	.084	30.0	30.0	5	17.2	0.015	4	3.1
30	1501-1	Zanjiran	2	23/6/94	0.20	.842	.374	1.092	20.0	22.0	8	501.4	0.11	12	3.7
31	1501-2	Zanjiran	2	23/6/94	0.20	.153	.106	.234	22.0	25.0	8	70.6	0.02	8	3.1
32	1501-3	Zanjiran	2	23/6/94	0.32	.197	.065	.168	22.0	25.0	3	41.7	0.02	12	3.8
33	1501-5	Zanjiran	2	24/6/94	0.27	.248	.097	.476	20.0	22.0	5.5	182.1	0.065	8	3.7
34	1501-6	Zanjiran	2	24/6/94	0.23	.250	.122	.198	25.0	30.0	4	49.6	0.035	5	3.6
35	1501-7	Zanjiran	2	24/6/94	0.23	1.352	.596	1.367	22.0	25.0	2.5	270.6	0.020	8	4.5
36	1501-8	Zanjiran	2	25/6/94	0.24	.154	.073	.214	20.0	25.0	5.5	128.9	0.03	12	3.6
37	1501-9	Zanjiran	2	25/6/94	0.24	.486	.238	.438	25.0	30.0	3.5	263.6	0.15	8	4.2
38	1523-1	Jovakan	1	6/7/94	0.26	.199	.144	.114	20.0	20.0	5	48.6	0.015	12	3.4
39	1523-2	Jovakan	1	7/7/94	0.20	.148	.073	.139	18.0	18.0	2.5	48.2	0.03	12	4.0
40	1523-3	Jovakan	1	7/7/94	0.20	.261	.166	.293	20.0	20.0	4	98.9	0.03	16	3.8
41	1523-4	Jovakan	1	9/7/94	0.20	.339	.153	.233	20.0	20.0	3.5	132.2	0.04	18	4.0
42	1519-1	Zarrat	1	10/7/94	0.20	.133	.050	.099	18.0	18.0	5	272.8	0.05	20	3.9
43	1523-5	Jovakan	1	10/7/94	0.20	.154	.095	.112	18.0	20.0	5	68.5	0.015	16	3.5
44	1518-2	Firouzabad	3	13/7/94	0.20	.126	.076	.080	6.0	10.0	2.5	96.1	0.04	16	4.2
45	1523-6	Jovakan	1	13/7/94	0.20	.288	.158	.263	18.0	18.0	2	49.2	0.06	16	4.2
46	1523-7	Jovakan	1	16/7/94	0.20	.129	.067	.142	18.0	18.0	4	555.8	0.03	16	4.3
47	1523-9	Jovakan	1	18/7/94	0.20	.183	.112	.184	21.0	21.0	2.5	24.1	0.015	14	3.8
48	1523-10	Jovakan	1	20/7/94	0.27	.190	.043	.113	10.0	10.0	4	70.1	0.02	15	3.7
49	1523-11	Jovakan	1	24/7/94	0.21	.129	.180	.224	21.0	21.0	6	83.9	0.025	12	3.4
50	1523-12	Jovakan	1	28/7/94	0.21	.307	.114	.260	21.0	21.0	5	48.6	0.015	12	3.4
51	1523-13	Jovakan	1	29/7/94	0.25	.183	.049	.088	28.0	28.0	5	136.8	0.04	12	3.7
52	1506-2	Hosseinih	4	31/7/94	0.20	.498	.130	.319	9.0	15.0	2	138.6	0.06	20	4.5
53	1506-3	Hosseinih	4	31/7/94	0.20	.146	.094	.257	12.0	18.0	2	69.5	0.04	20	4.3
54	1506-4	Hosseinih	4	31/7/94	0.28	1.788	.470	1.244	5.0	8.0	1.5	463.9	0.30	20	5.1
55	1506-5	Hosseinih	4	31/7/94	0.21	.272	.145	.185	12.0	18.0	1.5	116.6	0.08	20	4.7
56	1506-6	Hosseinih	4	31/7/94	0.21	.191	.060	.155	10.0	12.0	4.5	140.9	0.03	20	3.8
57	1506-7	Hosseinih	4	31/7/94	0.21	.118	.075	.084	15.0	20.0	3	83.2	0.04	18	4.1
58	1506-8	Hosseinih	4	31/7/94	0.21	.261	.141	.349	10.0	12.0	3	234.5	0.09	25	4.3
59	1506-9	Hosseinih	4	31/7/94	0.21	.234	.108	.144	12.0	12.0	3	117.5	0.04	20	4.1
60	1520-1	Kavar	2	1/8/94	0.25	.169	.106	.117	20.0	20.0	4	70.1	0.025	12	3.7
61	1506-10	Hosseinih	4	2/8/94	0.21	.184	.072	.080	18.0	20.0	1.5	41.4	0.03	18	4.4
62	1519-2	Zarrat	1	12/8/94	0.20	.118	.058	.148	12.0	18.0	5	193.2	0.04	15	3.8
63	1523-14	Jovakan	1	12/8/94	0.20	.206	.254	.124	21.0	21.0	4	197.3	0.05	16	4.0
64	1523-15	Jovakan	1	12/8/94	0.20	.380	.140	.338	18.0	18.0	4	197.3	0.05	16	4.0

No	Code BHRC	Station	Site	Event	HP filter (Hz)	PGA (H1) m/sec ²	PGA (V) m/sec ²	PGA (H2) m/sec ²	f max (H) Hz	f max (V) Hz	f c (Hz)	Stress Drop (Bar)	Ao m/sec	Hypo Dist. (km)	Mw calc.
65	1523-16	Jovakan	1	14/8/94	0.20	.181	.176	.176	22.0	22.0	4	98.9	0.04	14	3.8
66	1518-3	Fiروزabad	3	20/8/94	0.20	.134	.159	.118	7.0	10.0	2.5	96.1	0.03	20	4.2
67	1523-17	Jovakan	1	20/8/94	0.27	.172	.130	.246	18.0	20.0	5	193.2	0.03	18	3.8
68	1520-2	Kavar	2	26/8/94	0.20	.163	.114	.151	18.0	18.0	4	270.7	0.04	20	4.0
69	1523-18	Jovakan	1	26/8/94	0.20	.254	.148	.310	18.0	19.0	4	98.9	0.03	16	3.8
70	1523-19	Jovakan	1	28/8/94	0.20	.170	.041	.061	17.0	17.0	5	96.9	0.02	16	3.6
71	1523-20	Jovakan	1	28/8/94	0.24	.217	.097	.238	30.0	30.0	5	96.9	0.025	12	3.6
72	1523-21	Jovakan	1	7/9/94	0.24	.206	.067	.129	28.0	28.0	5	68.5	0.015	16	3.5
73	1523-22	Jovakan	1	9/9/94	0.24	.204	.102	.207	28.0	28.0	4.5	99.7	0.03	12	3.7
74	1533-1	Seifabad	1	10/9/94	0.20	.127	.098	.132	15.0	15.0	4	197.3	0.04	18	4.0
75	1523-23	Jovakan	1	19/9/94	0.28	.707	.296	.660	18.0	18.0	7	530.	0.10	16	3.8
76	1523-26	Jovakan	1	12/10/94	0.25	.049	.238	.075	20.0	20.0	3	14.8	0.01	18	3.5
77	1518-4	Fiروزabad	3	26/10/94	0.20	.126	.059	.140	6.0	8.0	2.5	96.1	0.04	16	4.2
78	1523-27	Jovakan	1	26/10/94	0.25	.168	.084	.308	20.0	20.0	3	83.2	0.04	14	4.0
79	1531	Lamerd	1	27/10/94	0.20	.317	.107	.112	25.0	30.0	6	333.9	0.05	16	3.8
80	1528-2	Fin	3	29/10/94	0.20	.250	.205	.237	18.0	20.0	3.5	132.2	0.05	16	4.0
81	1550-2	Masal	3	7/12/94	0.20	.125	.056	.120	6.0	8.0	3	117.5	0.045	16	4.1
82	1523-29	Jovakan	1	29/12/94	0.25	.366	.143	.372	18.0	18.0	2.5	270.6	0.08	22	4.5
83	1519-5	Zarrat	1	30/12/94	0.20	.243	.122	.215	19.0	21.0	4.5	396.8	0.085	18	4.1
84	1520-6	Kavar	2	30/12/94	0.20	.144	.087	.237	9.0	11.0	2.6	100.6	0.04	16	4.2
85	1523-30	Jovakan	1	30/12/94	0.25	.112	.051	.116	18.0	18.0	2	49.2	0.06	8	4.2
86	1573	Bagh-Malek	2	1/1/95	0.20	.134	.041	.073	10.0	11.0	2.5	135.7	0.06	16	4.3
87	1529-2	Lali	3	6/1/95	0.20	.104	.079	.159	12.0	15.0	4	98.9	0.03	12	3.8
88	1549-4	Ammarloo	3	6/1/95	0.20	.637	.487	.584	22.0	22.0	4	197.3	0.08	10	4.0
89	1529-3	Lali	3	7/1/95	0.20	.259	.150	.239	8.0	10.0	2	138.6	0.10	18	4.5
90	1523-31	Jovakan	1	12/1/95	0.25	.269	.069	.248	20.0	20.0	4	139.7	0.04	16	3.9
91	1528-22	Fin	3	24/1/95	0.25	.521	.279	.422	20.0	28.0	4	197.3	0.06	16	4.0
92	1528-23	Fin	3	24/1/95	0.25	.609	.269	.522	17.0	20.0	3.5	132.2	0.08	8	4.0
93	1528-24	Fin	3	24/1/95	0.25	.398	.267	.395	20.0	28.0	3	117.5	0.05	12	4.1
94	1528-26	Fin	3	24/1/95	0.25	1.795	.834	1.433	20.0	22.0	3	452.9	0.15	16	4.5
95	1528-27	Fin	3	24/1/95	0.25	.229	.112	.153	18.0	20.0	4	35.2	0.025	6	3.5
96	1528-28	Fin	3	24/1/95	0.25	.203	.126	.214	20.0	28.0	4	139.7	0.04	16	3.9
97	1528-29	Fin	3	24/1/95	0.25	.402	.209	.276	20.0	25.0	3.5	263.6	0.10	12	4.2
98	1528-10	Fin	3	24/1/95	0.20	1.652	.617	1.165	20.0	22.0	2.5	377.4	0.15	16	4.6
99	1528-11	Fin	3	24/1/95	0.23	.268	.121	.183	19.0	22.0	3	58.9	0.03	12	3.9
100	1528-12	Fin	3	24/1/95	0.23	.837	.512	.841	20.0	25.0	3.5	58.9	0.035	10	3.9
101	1528-13	Fin	3	24/1/95	0.23	.370	.132	.380	22.0	28.0	3	58.9	0.035	10	3.9
102	1528-14	Fin	3	24/1/95	0.23	.171	.137	.226	20.0	22.0	3.5	66.3	0.04	8	3.8
103	1528-15	Fin	3	24/1/95	0.23	.395	.275	.605	22.0	28.0	4	35.1	0.03	6	3.5
104	1528-16	Fin	3	24/1/95	0.34	.173	.141	.263	19.0	22.0	2.5	68.0	0.04	14	4.1
105	1528-17	Fin	3	24/1/95	0.20	.544	.214	.385	22.0	28.0	3.5	65.0	0.04	14	3.9
106	1528-18	Fin	3	24/1/95	0.25	.370	.134	.289	20.0	22.0	3.5	66.2	0.025	12	3.8
107	1528-19	Fin	3	24/1/95	0.25	.123	.119	.162	22.0	28.0	3	58.9	0.04	8	3.9
108	1528-20	Fin	3	24/1/95	0.25	.219	.112	.222	20.0	25.0	3.5	186.7	0.05	20	4.1
109	1528-21	Fin	3	24/1/95	0.25	.130	.105	.245	19.0	20.0	3	117.5	0.06	12	4.1
110	1528-4	Fin	3	24/1/95	0.20	.420	.256	.385	18.0	22.0	3.5	132.2	0.10	8	4.0
111	1528-5	Fin	3	24/1/95	0.20	.398	.264	.399	18.0	22.0	3	117.5	0.15	6	4.1
112	1528-6	Fin	3	24/1/95	0.20	.357	.210	.346	21.0	26.0	3.5	132.2	0.10	8	4.0
113	1528-7	Fin	3	24/1/95	0.20	.239	.190	.211	20.0	22.0	3.5	46.9	0.03	8	3.7
114	1528-8	Fin	3	24/1/95	0.25	.406	.229	.251	18.0	22.0	3.5	186.7	0.06	16	4.1
115	1528-9	Fin	3	24/1/95	0.18	.435	.259	.469	20.0	22.0	3.5	132.2	0.06	14	4.0
116	1528-30	Fin	3	25/1/95	0.25	.365	.223	.277	20.0	20.0	3.5	93.6	0.035	12	3.9
117	1528-31	Fin	3	25/1/95	0.25	.171	.115	.184	15.0	18.0	3.5	132.2	0.04	16	4.0
118	1631-1	Musian	3	27/1/95	0.38	.184	.112	.304	16.0	18.0	3	117.5	0.035	16	4.1
119	1592	Golbaf	3	17/2/95	0.28	.148	.112	.100	8.0	12.0	1.5	41.4	0.05	12	4.4
120	1535-1	Rudbar	3	7/3/95	0.20	.255	.164	.274	18.0	20.0	4	139.7	0.055	10	3.9
121	1564-1	Khanzanun	1	9/3/95	0.20	.173	.125	.117	12.0	18.0	2	34.8	0.02	16	4.1
122	1650-1	Fiروزabad	3	25/3/95	0.38	.302	.191	.294	6.0	11.0	1.5	166.4	0.10	12	4.7
123	1545-2	Kavar	2	4/4/95	0.20	.144	.071	.159	9.0	11.0	2.5	48.2	0.03	12	4.0
124	1590-1	Sisakht	1	6/4/95	0.25	.261	.317	.273	30.0	33.0	9	452.9	0.05	16	3.5
125	1562-2	Zarrat	1	16/4/95	0.20	.275	.185	.160	12.0	18.0	4		0.10	16	4.2
126	1655	Saman	2	18/4/95	0.38	.182	.088	.136	25.0	28.0	5	44.0	0.01	14	3.4
127	1558	Shabankareh	4	2/5/95	0.20	.132	.096	.118	10.0	11.0	4	67.9	0.015	18	3.7
128	1529-1	Lali	3	14/5/95	0.20	.091	.036	.137	10.0	12.0	4	197.3	0.04	18	4.0
129	1535-3	Rudbar	3	17/5/95	0.20	.228	.111	.123	12.0	18.0	2	49.2	0.035	12	4.2

No	Code BHRC	Station	Site	Event	HP filter (Hz)	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	f max (H) Hz	f max (V) Hz	fc (Hz)	Stress Drop (Bar)	Ao m/sec	Hypo Dist. (km)	Mw calc.
130	1551-1	Shabastar	1	17/5/95	0.20	.247	.314	.138	11.0	19.0	4	197.3	0.04	24	4.0
131	1546	Tasuj	2	18/5/95	0.20	.168	.083	.127	15.0	18.0	2.5	191.6	0.06	20	4.4
132	1551-3	Shabastar	1	18/5/95	0.20	.133	.062	.104	18.0	22.0	4	70.05	0.08	24	4.2
133	1552	Pol-e Sefid	4	2/6/95	0.20	.308	.133	.181	20.0	25.0	3.5	186.7	0.04	18	4.1
134	1635-1	Pol-e Sefid	4	2/6/95	0.38	.306	.133	.181	20.0	25.0	3.5	186.7	0.04	18	4.1
135	1576	Gavbandi	3	18/6/95	0.20	.150	.158	.228	25.0	30.0	5	75.5	0.02	12	3.5
136	1542	Ammarloo	3	10/7/95	0.20	.207	.077	.091	18.0	20.0	4	49.6	0.02	12	3.6
137	1635-2	Pol-e Sefid	4	27/7/95	0.38	.171	.181	.078	18.0	25.0	3	82.2	0.025	20	4.0
138	1557	Delvar	2	28/7/95	0.20	.133	.043	.061	18.0	22.0	4	100.6	0.02	20	3.8
139	1620-2	Doab	3	28/7/95	0.28	.643	.230	.385	20.0	25.0	3	113.2	0.03	20	4.1
140	1620-3	Doab	3	14/8/95	0.28	.155	.067	.069	18.0	22.0	4.0	70.1	0.02	18	3.7
141	1620-4	Doab	3	15/8/95	0.28	.331	.135	.148	20.0	30.0	3.5	93.6	0.03	18	3.9
142	1631-2	Musian	3	16/8/95	0.38	.074	.035	.129	11.0	15.0	4	70.1	0.02	16	3.7
143	1549-1	Ammarloo	3	7/9/95	0.20	.170	.261	.478	11.0	12.0	3.5	75.4	0.025	12	3.7
144	1549-2	Ammarloo	3	21/9/95	0.28	.136	.164	.164	15.0	17.0	4	35.1	0.015	12	3.5
145	1540	Rasht (Hous.)	3	13/10/95	0.40	.122	.031	.102	6.0	8.0	1	68.9	0.09	16	4.9
146	1637-1	Rasht (Hous.)	3	13/10/95	0.38	.123	.031	.103	7.0	8.0	0.7	66.6	0.09	16	5.2
147	1564-2	Khanzanun	1	23/10/95	0.20	.525	.244	.563	12.0	18.0	3	83.2	0.06	8	4.9
148	1620-5	Doab	3	26/10/95	0.28	.149	.050	.073	22.0	35.0	6	83.9	0.01	20	3.4
149	1590-3	Sisakht	1	2/11/95	0.28	.186	.159	.191	30.0	30.0	5.5	129.7	0.025	15	3.6
150	1538	Kolur	1	3/11/95	0.20	.268	.151	.360	40.0	40.0	6	181.2	0.06	16	3.6
151	1544	Silvaneh	4	14/11/95	0.20	.434	.198	.228	10.0	12.0	2.5	191.6	0.10	16	4.4
152	1560-2	Lali	3	24/11/95	0.20	.171	.134	.165	12.0	18.0	4	197.3	0.04	20	4.0
153	1560-3	Lali	3	25/11/95	0.20	.195	.183	.143	8.0	12.0	5	193.2	0.035	10	3.3
154	1560-5	Lali	3	27/11/95	0.20	.197	.143	.171	15.0	18.0	3	45.2	0.03	8	3.8
155	1590-4	Sisakht	1	14/12/95	0.28	.241	.293	.267	28.0	30.0	6	105.8	0.02	14	3.5
156	1549-3	Ammarloo	3	29/12/95	0.20	.300	.124	.244	22.0	28.0	3.5	93.6	0.04	12	3.9
157	1602-3	Kavar Dam	2	31/12/95	0.28	.125	.031	.112	8.0	10.0	4.5	280.9	0.035	32	4.0
158	1571-1	Shabankareh	4	23/1/96	0.20	.402	.325	.296	18.0	20.0	3	120.8	0.05	16	4.1
159	1571-2	Shabankareh	4	23/1/96	0.25	.236	.123	.087	15.0	18.0	6	120.8	0.02	16	3.5
160	1571-3	Shabankareh	4	23/1/96	0.30	.086	.175	.314	12.0	16.0	5	125.8	0.025	16	3.7
161	1571-10	Shabankareh	4	24/1/96	0.25	.534	.418	.837	11.0	18.0	3	679.4	0.35	24	4.6
162	1571-12	Shabankareh	4	24/1/96	0.25	.103	.104	.117	11.0	15.0	6	236.4	0.03	20	3.7
163	1571-13	Shabankareh	4	24/1/96	0.25	.123	.092	.193	10.0	18.0	5.5	182.1	0.035	18	3.7
164	1571-14	Shabankareh	4	24/1/96	0.24	.117	.077	.214	10.0	12.0	5.5	182.1	0.035	16	3.7
165	1571-15	Shabankareh	4	24/1/96	0.24	.167	.091	.159	10.0	12.0	5.5	128.9	0.03	15	3.6
166	1571-17	Shabankareh	4	24/1/96	0.28	.105	.105	.146	18.0	22.0	6.5	150.7	0.025	17	3.5
167	1571-18	Shabankareh	4	24/1/96	0.28	.032	.047	.116	18.0	20.0	6	167.4	0.025	18	3.5
168	1571-19	Shabankareh	4	24/1/96	0.28	.253	.101	.167	12.0	18.0	5.5	363.2	0.06	16	3.8
169	1571-20	Shabankareh	4	24/1/96	0.28	.102	.061	.133	12.0	18.0	6	333.9	0.05	16	3.8
170	1571-21	Shabankareh	4	24/1/96	0.28	.116	.078	.172	12.0	15.0	6	236.4	0.04	16	3.7
171	1571-22	Shabankareh	4	24/1/96	0.28	.080	.152	.499	18.0	22.0	3.5	140.9	0.04	16	4.0
172	1571-23	Shabankareh	4	24/1/96	0.28	.109	.151	.163	15.0	20.0	6	167.4	0.03	16	3.6
173	1571-24	Shabankareh	4	24/1/96	0.28	.109	.035	.083	9.0	11.0	4	197.3	0.035	20	4.0
174	1571-25	Shabankareh	4	24/1/96	0.28	.199	.145	.260	15.0	19.0	3.5	110.1	0.025	20	3.9
175	1571-4	Shabankareh	4	24/1/96	0.44	.082	.164	.342	15.0	18.0	5	171.1	0.02	17	3.7
176	1571-5	Shabankareh	4	24/1/96	0.47	.121	.134	.380	12.0	18.0	4	120.8	0.03	16	3.8
177	1571-6	Shabankareh	4	24/1/96	0.47	.100	.166	.246	15.0	18.0	4	80.5	0.02	16	3.7
178	1571-7	Shabankareh	4	24/1/96	0.47	.199	.267	.632	15.0	20.0	4	768.	0.04	17	3.9
179	1571-9	Shabankareh	4	24/1/96	0.52	.083	.064	.179	11.0	15.0	4	64.2	0.015	17	3.7
180	1583-5	Saadabad	1	24/1/96	0.25	.227	.046	.215	20.0	22.0	2.5	96.1	0.03	22	4.2
181	1583-6	Saadabad	1	24/1/96	0.25	.152	.092	.172	18.0	18.0	3.5	186.7	0.035	25	4.1
182	1571-26	Shabankareh	4	25/1/96	0.28	.236	.270	.811	20.0	25.0	4	201.3	0.04	20	4.0
183	1571-27	Shabankareh	4	25/1/96	0.28	.089	.096	.121	11.0	15.0	6	236.4	0.035	20	3.7
184	1571-28	Shabankareh	4	25/1/96	0.28	.213	.187	.277	12.0	15.0	5.5	362.2	0.06	20	3.9
185	1571-29	Shabankareh	4	25/1/96	0.28	.214	.144	.237	11.0	19.0	5.5	280.9	0.08	20	4.0
186	1571-31	Shabankareh	4	25/1/96	0.28	.043	.093	.135	13.0	20.0	4	50.3	0.01	20	3.6
187	1571-33	Shabankareh	4	26/1/96	0.28	.951	.787	1.771	11.0	17.0	5.5	182.1	0.025	20	3.7
188	1571-36	Shabankareh	4	26/1/96	0.28	.045	.061	.140	12.0	16.0	5.5	128.9	0.025	15	3.6
189	1701-1	Ardebil	4	28/2/97	0.15	1.639	.599	1.201	6.0	11.0	0.4	69.2	0.8	32	6.3

Chapitre 5

Durée et Énergie des Mouvements Forts

Résumé Ce chapitre est consacré à l'étude de différents paramètres "énergétiques", c'est à dire liés à l'énergie véhiculée par les accélérogrammes (durée, accélération moyenne quadratique, "énergie"). Comme dans les autres chapitres, une distinction est faite entre Zagros et le reste de l'Iran, et la dépendance de chacun de ces paramètres en fonction de la magnitude, de la distance et des conditions de site est précisée grâce à des régressions. L'influence de ces dernières est d'ailleurs trouvée très faible, surtout pour la durée.

Duration and Energy Content of the Strong Motions in Iran

Mehdi Zaré, Pierre-Yves Bard and Mohsen Ghafory-Ashtiany

Article soumis au "Journal of Earthquake Engineering"

Abstract The energy content and the strong motion duration are studied in Iran. Several parameter [root mean square acceleration, a_{rms} , the "energy of acceleration", e_a , proportional to Arias Intensity, and strong motions duration] are calculated for a data-base of 468 three component accelerograms, all recorded during the last 24 years in Iran. Empirical relationships are established for the strong motion duration, as a function of e_a , PGA on one side, and moment magnitude and hypocentral distances on the others. The dependence of e_a and a_{rms} with magnitude and distance is studied as well. Investigations on the possible influence of site conditions on the duration, did not point out any significant dependence in this regard. The probable trends in the results of Zagros region may be studied with more precise data. For such trends, there is no more explanation with this quantity of the data.

5.1 Introduction

The strong motion network in Iran has provided a significant amount of records from various regions of the country for the last 24 years. This network was equipped first with Kinometrics SMA-1 analog instruments (1975) which have been gradually replaced and densified with SSA-2 digital instruments after the Manjil earthquake of 1990, $M_w 7.4$, in NW Iran. The number of installed instruments in this network was reported to be about 1000 stations by the end of 1997. The stations have been mainly chosen within the cities or villages for an easy maintenance. A

listing of these data is published by BHRC, the organism that maintains this network presently in Iran (BHRC 1993).

The scope of this study is to investigate the energy content of Iranian data, and to derive empirical relationships for the energy-related parameters: strong motion duration, e_a and a_{rms} . The data-set used in this study, already presented in Bard et al. (1998), Zaré et al. (1999b), consists of 468 three component records. The source parameters were derived from teleseismic records for 190 events (279 recordings) (Bard et al 1998), while moment magnitudes and hypocentral distances were derived from the strong motion data themselves for 185 events (189 records) (Zaré et al 1999b).

The methodology of the study is explained first. The seismogenic zones in Iran, in view point of the strong motions, are detailed. The relationships for the energy content and duration are discussed. The empirical attenuation relationships are established and presented for the duration, e_a and a_{rms} .

5.2 Seismogenic zones in Iran and site conditions

The seismotectonics of Iran was first investigated by Nabavi (1976), Berberian (1976, 1977, 1981, ...etc), and more recently in the seismotectonic reports after each destructive earthquake in Iran (i.e. Zaré 1995, Zaré 1997). The main seismogenic zones in Iran are distinguished based on tectonic and neotectonic factors. To define such seismotectonic zones, it is necessary to have sufficient neotectonic diagnosis as well as the seismic source data. Previous works are mostly concentrated on studies on focal mechanisms and focal depths, as well as on seismicity studies (Ambraseys and Melville 1982, Jackson and McKenzie 1984, Berberian 1995, ... etc).

Some differences in seismicity rates are obvious at least between the two regions of Iran: Zagros in SW and west, and Alborz-Central Iran, in the center, north and east (Figure 5.1). The Zagros thrust fault zone is the main geologic frontier between the Zagros and the rest of the country (mainly Central Iran). The time of the event, the distance to source and the exact timing on the digital records (if accessible) were the criteria to attribute each record to the seismic events in these zones. The pre-existing seismic data from Zagros area shows higher seismic activity rate than the other regions. In this area the middle range magnitudes ($M 4-6$) are more frequent (Figure 5.2). In Alborz-Central Iran zone, the earthquake are less frequent with higher magnitudes than Zagros (Figure 5.2), and more destructive. The Tabas earthquake of (1978, $M_w 7.4$, Central-Iran) and Manjil earthquake (1990, $M_w 7.3$, Alborz belt) are examples of such destructive events. Most of the focal mechanisms in Iran (in Zagros and in other regions)

are compressional and strike slip (Bard et al 1998) in relation with the local plate tectonics context.

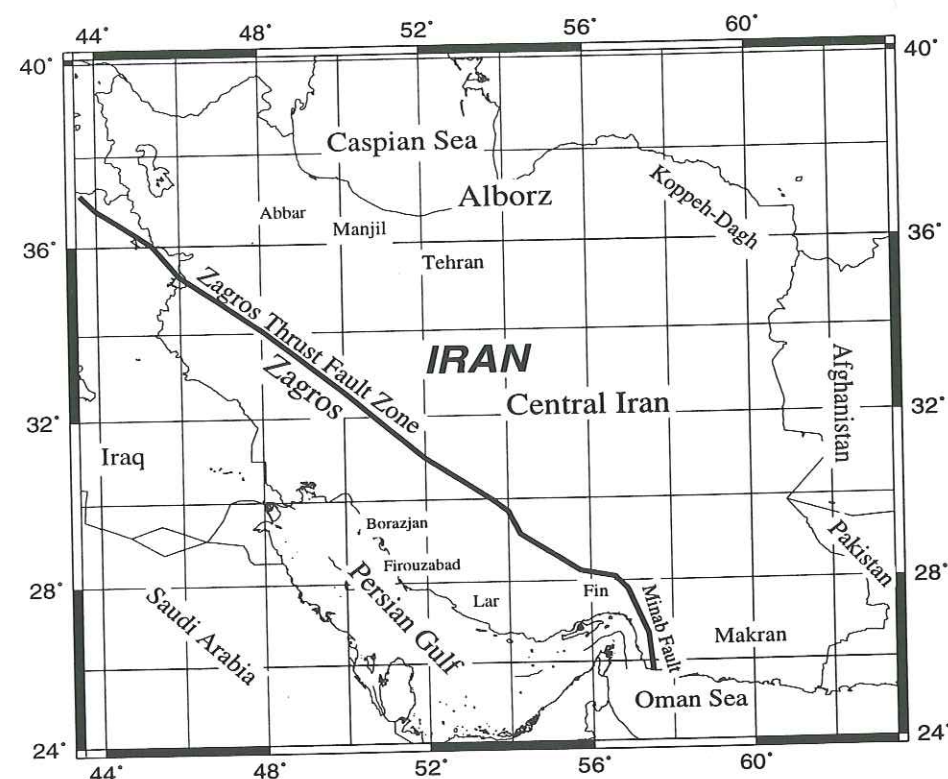


FIG. 5.1 – The studied area; the regions discussed in the text are shown.

The accelerometric data-base of Iran (Bard et al 1998) is not homogeneous; most of the data are recorded in Zagros, but no record exists from Makran (due to the lack of important earthquake in the last decades, and where few stations have been installed). The reasons for the fewer stations in this region were the sparse population in Makran region. Since the most destructive earthquakes have shocked the Alborz and Central-Iran region, the most distant records are obtained in these two regions (Figure 5.2).

The site conditions for the Iranian strong motions have already been studied (Zaré et al 1999a). Site class 1 is defined as sites that do not exhibit any significant amplification below 15 Hz. It corresponds to rock and stiff sediment sites with an average S-wave velocity over the top 30 meters in excess of 700m/sec. Site class 2 is determined as sites for which the receiver function (RF) exhibits a fundamental peak exceeding 3 at a frequency located between 5 and 15 Hz. It was shown to correspond to stiff sediments and/or soft rocks with V_{s30} between 500 and 700 m/sec. Site class 3 is defined as sites for which RF shows peaks exceeding 3 between 2 and 5Hz, and corresponds to alluvial sites with V_{s30} between 300 and 500 m/sec. Finally site class 4

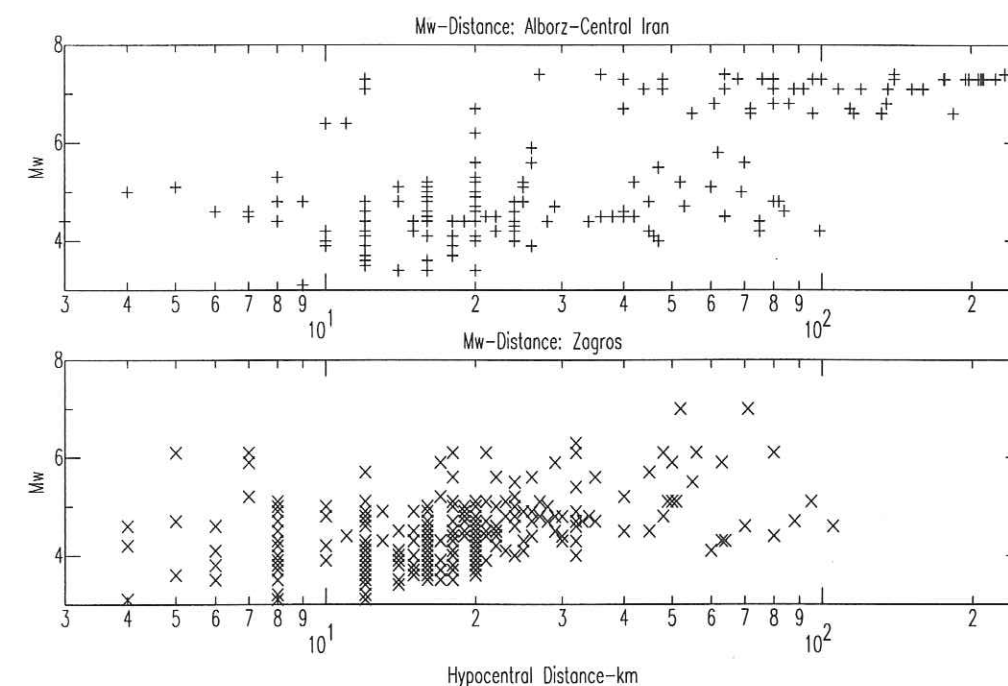


FIG. 5.2 – The M_w -Hypocentral distance distribution for two areas in Iran.

is defined as sites for which RF exhibits a fundamental peak exceeding 3 below 2Hz, and it may be viewed as corresponding to thick soft alluvium. This ranking was the result of geotechnical measurements on 24 sites (compressional and shear wave velocity and microtremors) and the calculation of the receiver function using the three component accelerograms.

5.3 Methodology

The duration of strong motions is defined in different ways. Some authors have used the "bracketed duration" (Bullen and Bolt 1985), which is the elapsed time window between the first and last acceleration excursions greater than a given level (i.e. 0.05g) (Page et al 1975). Another known definition in the earthquake engineering literature is the "cumulative duration" (Bullen and Bolt 1985), which is based on the concept of the cumulative energy obtained by integrating the squared accelerations. In this concept, duration is the time interval required to accumulate a predefined fraction of total energy (95% for Husid et al., 1969; 90% for Trifunac and Brady, 1975; and 70% for some other authors). Trifunac and Brady (1975) take the part between of 5% and 95% of total energy.

The Fourier amplitude spectra (A_ω) of an acceleration time-history, $a(t)$, is the absolute value of the Fourier transform of $a(t)$ (Vanmarke and Lai 1980);

$$A_\omega = \left| \int_{-\infty}^{+\infty} a(t) e^{-i\omega t} dt \right| = \left| \int_0^{t_0} a(t) e^{-i\omega t} dt \right|$$

ω is the angular frequency in rad/sec, $i = \sqrt{-1}$ and t_0 is the length of the accelerogram (sec). To explain how the total strong motion energy is distributed over frequency, one may use the squared Fourier amplitude spectrum, $A^2(\omega)$. The integral of $A^2(\omega)$ over the frequencies is a representative for the total strong motion "energy", related to the Arias intensity, I_0 [Arias 1970]. This parameter shows the total energy per unit mass for the entire acceleration record for all single degree of freedom oscillators;

$$I_0 = \frac{\pi}{2g} \int_0^{t_0} a^2(t) dt$$

We have considered here a related formulation:

$$e_a = \int_0^{t_0} a^2(t) dt = \int_{-\infty}^{+\infty} a^2(t) dt = \frac{1}{2\pi} \int_{-\infty}^{+\infty} A^2(\omega) d(\omega) = \frac{1}{\pi} \int_0^\infty A^2(\omega) d(\omega)$$

In this article, we name this quality the "energy of acceleration" (e_a):

$$e_a = \int_0^{t_0} a^2(t) dt$$

a_{rms} is the square root of the average of the squared ordinates for a given duration, t_2-t_1 , (Udwadia and Trifunac 1974):

$$a_{rms} = \left(\frac{1}{t_2-t_1} \int_{t_1}^{t_2} a^2(t) dt \right)^{\frac{1}{2}}$$

$$a_{rms} = \sqrt{\frac{\Sigma e_a}{t_2-t_1}}$$

McCann and Shah (1979) have defined an evolutionary RMS function (CRF), which represents the average rate of energy as a function of time:

$$CRF(t) = \left(\frac{1}{t} \int_0^t a^2(t) dt \right)^{\frac{1}{2}}$$

CRF allows another definition of duration, (the end of the signal is the time after which CRF(t) decreases).

The cumulative integral of squared acceleration for a record of Manjil earthquake ($M_w 7.3$, 20 June 1990, hypocentral distance= 40km) obtained at Abbar (site class: rock, Figure 5.1) is shown in Figure 5.3. This record is obtained in Alborz ranges in northern Iran. The duration for this time-history (taking to account the intervals of 5% to 95%) are 31.92 and 35.06 for the horizontals and 35.96 for vertical component, respectively. These values are 8.64 and 20.68 for horizontals and 13.52 for vertical components, respectively, applying the intervals of 5% to 75%.

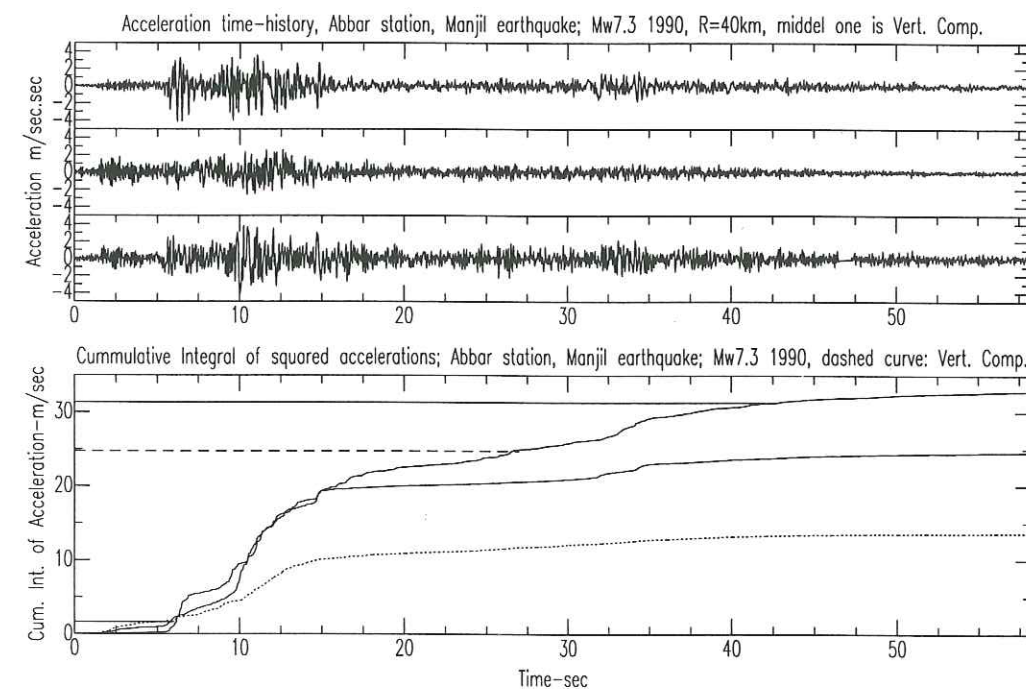


FIG. 5.3 - The time-history of the acceleration (up) and the cumulative integral of squared acceleration (down), for the Abbar record (Manjil, Iran earthquake of 20 June 1990, $M_w 7.3$). The lines show the 5% and 95% limits, and a dashed line shows the 75% limit for the horizontal component that has the highest values. The vertical component is shown by dotted line as well.

Vanmarke and Lai (1980) have proposed an approximate relationship between the a_{rms} and PGA based on the random vibration theory:

$$r = \frac{a_{max}}{a_{rms}} \quad (5.1)$$

with T_0 for the strong motion duration and Having

$$e_a = \frac{T_0 \cdot a_{rms}^2}{0.90} \quad (5.2)$$

with an approximation we have:

$$e_a \approx T_0 \cdot a_{rms}^2 \quad (5.3)$$

With (5.1) and (5.2), we have:

$$T_0 = r^2 \cdot \frac{e_a}{a_{max}^2} \quad (5.4)$$

We therefore computed the ratio $\frac{e_a}{a_{max}^2}$ for all our records, and investigated its relationship with the actual strong motion duration, T_0 . We have studied as well the dependence of T_0 , e_a and a_{rms} as a function of the magnitude and distance.

5.4 Results

The results of our calculations are presented in a Table in Appendix 5.1. For each component of the records the values of e_a , strong motion duration $T - 0$ and a_{rms} , are given based on the definition of Udvardi and Trifunac (1974) (5%-75%), and Trifunac and Brady (1975) (5% to 95%).

5.4.1 Comparison of Strong Motion Intervals: 5%-95% and 5%-75%

The different intervals of 5% to 95% and 5% to 75% are examined in this study. The general tendency is that: the a_{rms} values calculated for 5% to 75% intervals, are equal to or larger than a_{rms} obtained by 5% to 95% intervals (Appendix 5.1).

The relationship for a_{rms} and the duration values calculated by these two intervals are shown in Figures 5.4 to 5.7. The linear relationship between a_{rms1} (5%-75%) and a_{rms2} (5%-95%) is

$$a_{rms1} = b \cdot a_{rms2} + \sigma \cdot P \quad (5.5)$$

where b is the coefficient, σ is standard deviation, P is the percentile index. The coefficients for the entire of the data-base are supplied in table 5.1:

Table 5.1: Result of the regression for relationship (5.5)

Data/comp.	b	R(Coef.Corr.)	Sigma
Iranian data (Vert. comp)	1.124	0.981	0.0014
Iranian data (Hori. comp)	1.375	0.981	0.0020

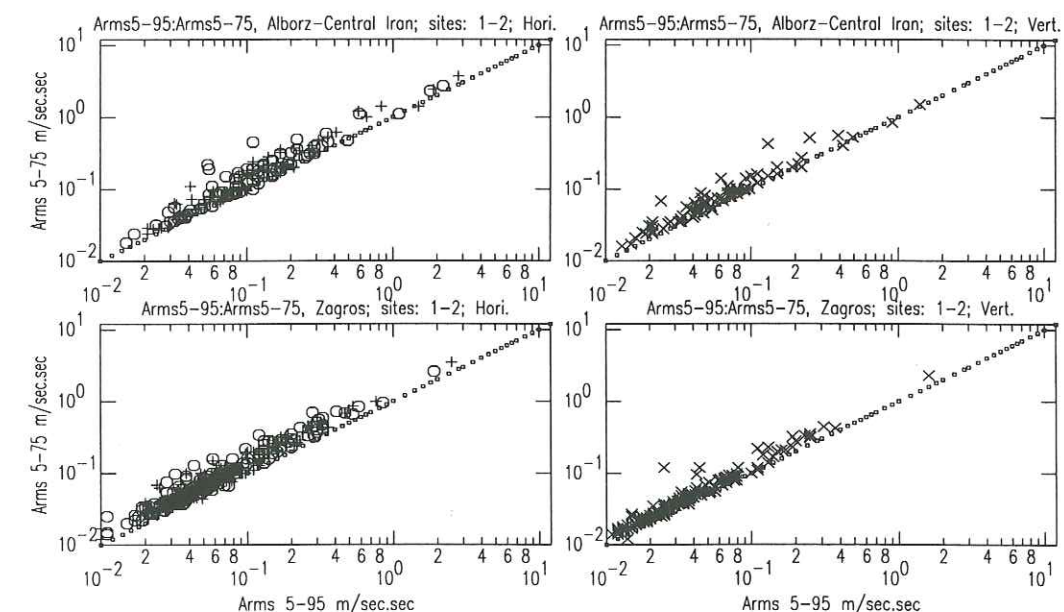


FIG. 5.4 - The a_{rms} values calculated for different intervals are plotted against each other; site classes 1 and 2, for two areas; two different symbols in the left side figures stand for two horizontal components (Alborz-Central-Iran top, Zagros bottom).

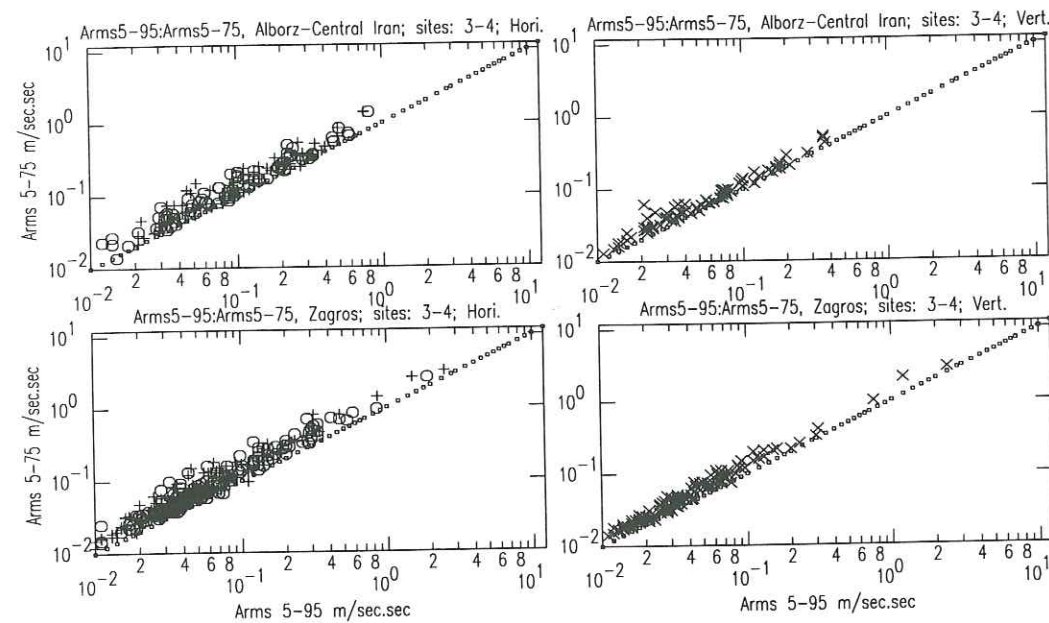


FIG. 5.5 – The a_{rms} values calculated for different intervals are plotted against each other; site classes 3 and 4, for two areas; two different symbol in the left side figures stand for two horizontal components (Alborz-Central-Iran top, Zagros bottom).

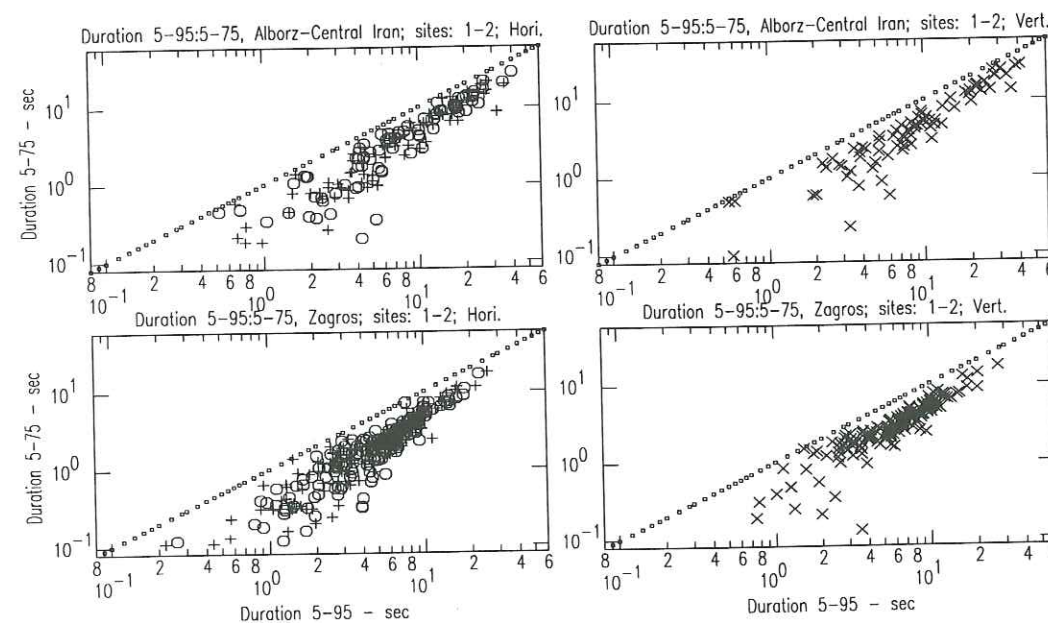


FIG. 5.6 – The strong motion duration values calculated for different intervals are plotted against each other; site classes 1 and 2, for two areas; two different symbol in the left side figures stand for two horizontal components (Alborz-Central-Iran top, Zagros bottom).

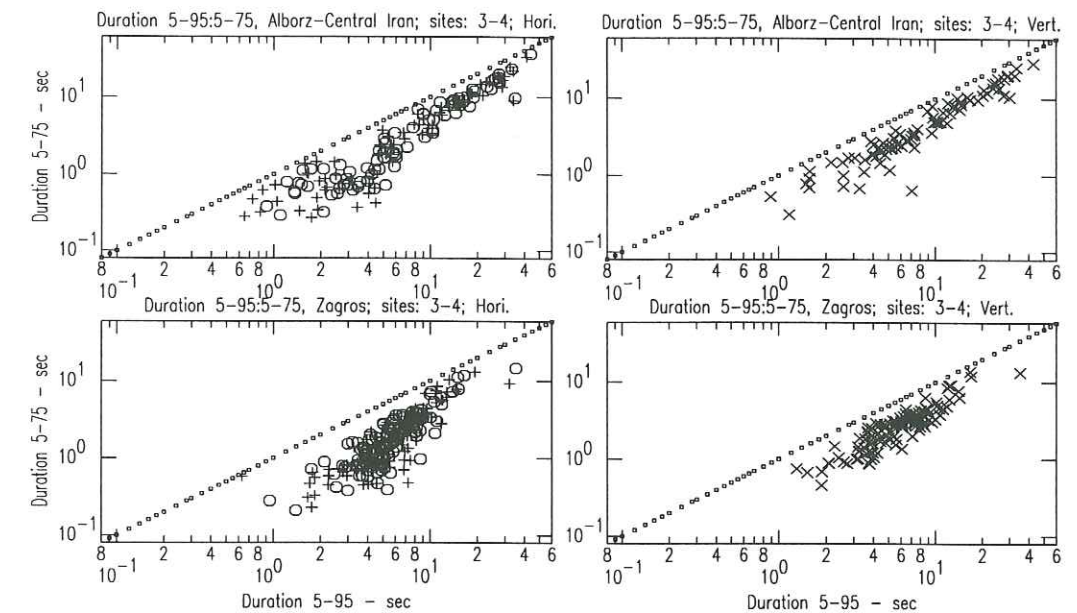


FIG. 5.7 – The strong motion duration values calculated for different intervals are plotted against each other; site classes 3 and 4, for two areas; two different symbol in the left side figures stand for two horizontal components (Alborz-Central-Iran top, Zagros bottom).

The linear relationship for the durations estimated for 5%-75% intervals (T_{01} : 5-75) and 5%-95% intervals (T_{02} : 5-95) may be shown in similar way;

$$T_{01} = b \cdot T_{02} + \sigma \cdot P \quad (5.6)$$

The results for such relationship using the entire of the Iranian data are given in table 5.2:

Table 5.2: Result of the regression for relationship (5.6)

Data/comp.	b	R(Coef.Corr.)	Sigma
Iranian data (Vert. comp)	0.578	0.984	1.460
Iranian data (Hori. comp)	0.541	0.927	1.558

In this study, as the differences in data (grouped in four sites classes) were not very clear for a_{rms} and duration estimations, the data are regrouped in two groups; group 1 which represent the original site classes of 1 and 2, and the group 2 replaced the site classes 3 and 4. The comparison of the duration for group 1 (classes 1-2) and group 2 (classes 3-4) is shown in Figures 5.4 and 5.5 for Zagros and Alborz-Central Iran region. The duration estimations for

site group 2 in Alborz-Central Iran are found in the range of 0.8 to 40 seconds, while in the Zagros region the durations are calculated in the range of 2 to 12 seconds (Figure 5.5). The relationship between the a_{rms} estimations with the two intervals, for the site groups 1 and 2, for Zagros and Alborz-Central Iran regions, are shown in Figures 5.6 and 5.7.

5.4.2 Empirical Relationships for the Strong Motion Duration in Iran

The duration is one of the most important strong motion parameters. Several researchers have declared that the duration and the energy content of the strong motions may reveal the seismic performance of the structures (Jeong and Iwan 1988, Uang and Bertero 1990). Recent developments in different countries provide the possibility to examine the different method to define such parameters using different catalogues (Koliopoulos et al 1998).

Attenuation of Duration

To investigate the dependence of duration with M_w and hypocentral distance, a linear model is first considered. A one-step method is applied, in which all the parameters are determined simultaneously by maximizing the likelihood of the set of observations. This approach, which is used by Joyner and Boore (1993) and Brillinger and Preisler (1984, 1985), led to results comparable with the two-step method (Boore et al 1994). The two-step method is used further in this article to find the attenuation of a_{rms} and ea.

All of the duration values are plotted against M_w and hypocentral distances in Figure 5.8. These data similarly shown in Figures 5.9 and 5.10 for the two different geographical zones (Zagros, Alborz-Central Iran) and the two site groups, against M_w and hypocentral distances, respectively. Such a relationship was already proposed by Trifunac and Brady (1975) as;

$$T_0 = a \cdot M_w + b \cdot X + \sigma \cdot P \quad (5.7)$$

where X is the hypocentral distance in kilometers. The results of the regression using relationship (5.7) are presented in Table 5.3. The residuals of the predicted T_0 values by (5.7) are shown in Figures 5.11 and 5.12 against hypocentral distance and M_w , respectively.

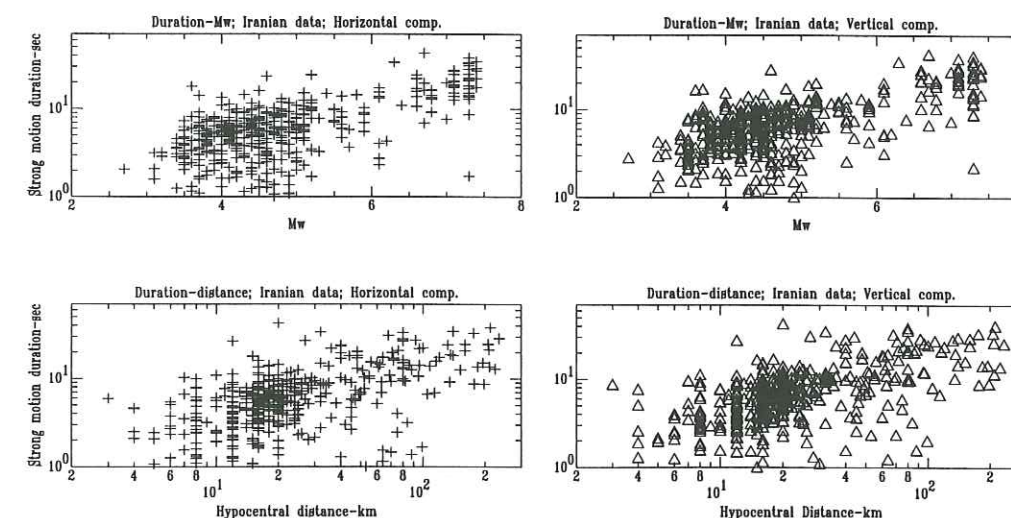


FIG. 5.8 – Distribution of duration values against M_w (top) and Hypocentral Distances (bottom) for entire data of Iran.

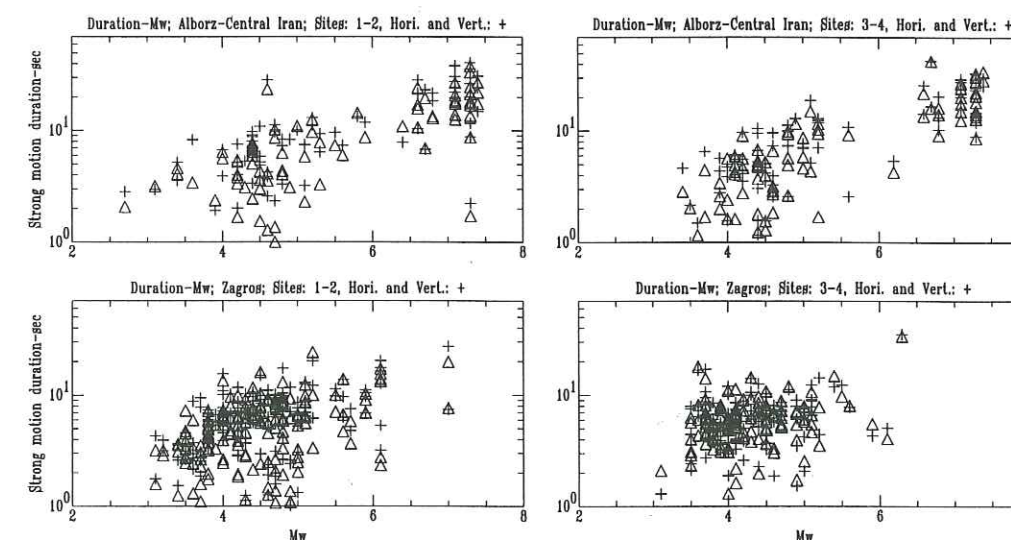


FIG. 5.9 – Distribution of duration values against M_w for two areas. (triangles for horizontal and crosses for vertical components), left; site group 1, right; site group 2, Alborz-Central Iran; bottom

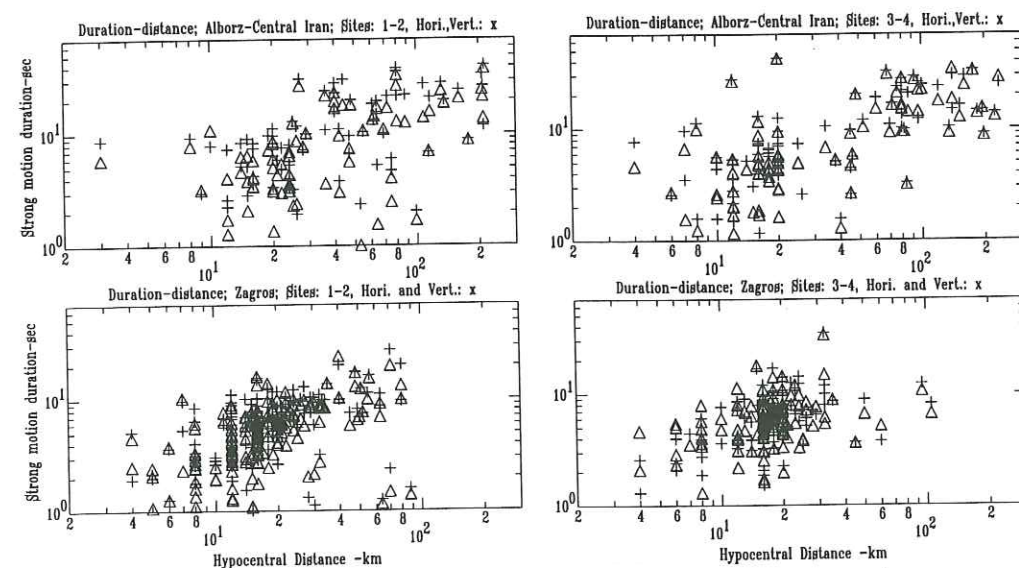


FIG. 5.10 – Distribution of duration values against hypocentral Distances for two areas. (triangles for horizontal and crosses for vertical components), left; site group 1, right; site group 2, Alborz-Central Iran; bottom

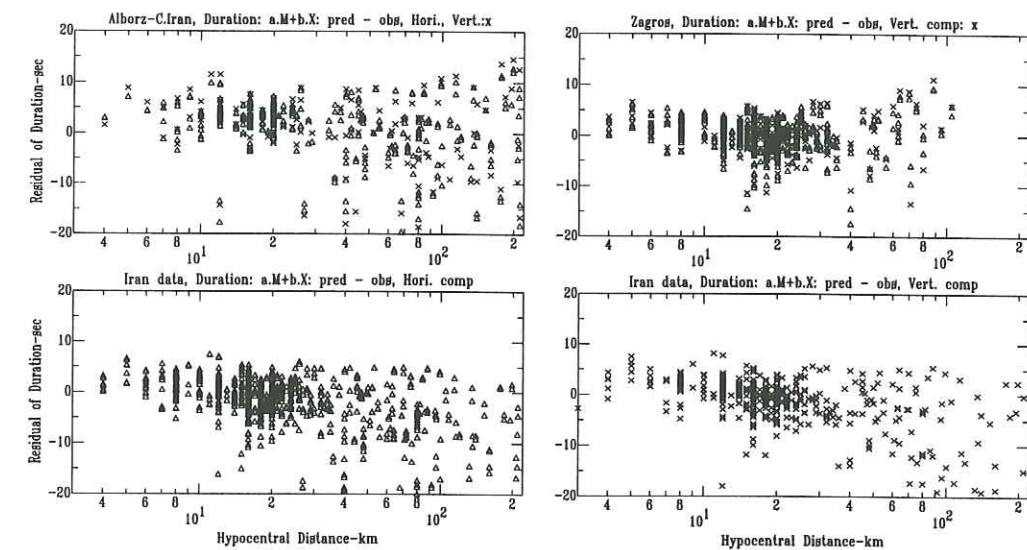


FIG. 5.11 – Residual of the predicted duration values (obtained by relationship 5.7), against hypocentral distances, in Alborz-Central Iran, Zagros and entire of the data base. Horizontal and vertical components are considered. (triangles for horizontal and crosses for vertical components)

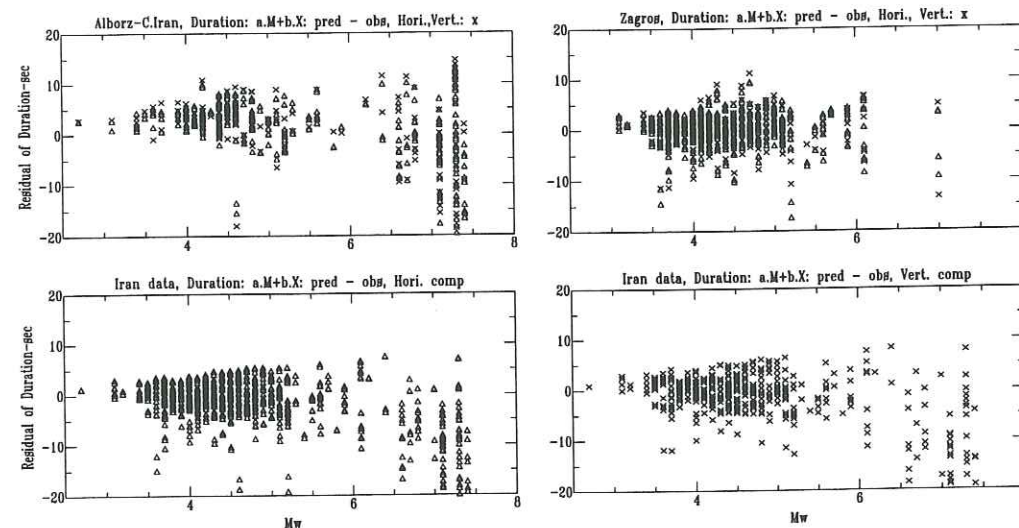


FIG. 5.12 – Residual of the predicted duration values (obtained by relationship 5.7), against M_w , in Alborz-Central Iran, Zagros and entire of the data base; the horizontal and vertical components are considered. (triangles for horizontal and crosses for vertical components)

Table 5.3: Result of the regression for relationship (5.7)

Region/comp.	a	b	R(Coef. Corr.)	Sigma
Central Iran, Alborz (Vert.)	1.799	0.053	0.622	5.024
Central Iran, Alborz (Hori.)	1.477	0.052	0.651	6.760
Zagros (Vertical comp.)	1.140	0.084	0.484	3.453
Zagros (Horizontal comp.)	1.085	0.064	0.425	3.326
Iranian data (Vertical)	1.356	0.073	0.676	5.056
Iranian data (Horizontal)	1.181	0.065	0.653	4.730

A slightly different form of the distance-magnitude relationship was also tried, corresponding to formula 5.8, where the $\log T_0$ and $\log X$ are replacing the linear terms of 5.7:

$$\log T_0 = a \cdot M_w + b \cdot \log X + \sigma \cdot P \quad (5.8)$$

The coefficients using this equation are presented in table-5.4:

Table 5.4: Result of the regression for relationship (5.8)

Region/comp.	a	b	R(Coef. Corr.)	10^{Sigma}
Central Iran, Alborz (Vert.)	0.111	0.217	0.693	0.277
Central Iran, Alborz (Hori.)	0.097	0.202	0.615	0.338
Zagros (Vertical comp.)	0.046	0.445	0.488	0.219
Zagros (Horizontal comp.)	0.047	0.404	0.410	0.240
Iranian data (Vertical)	0.080	0.323	0.705	0.287
Iranian data (Horizontal)	0.071	0.304	0.637	0.287

The residuals of the $\log T_0$ predicted values by 5.8 are presented in Figures 5.13 and 5.14, against distance and M_w , respectively. These results reveal that the Alborz-Central Iran data are more sensible to the variation of the magnitudes, where the Zagros data show more sensibility to the hypocentral distances.

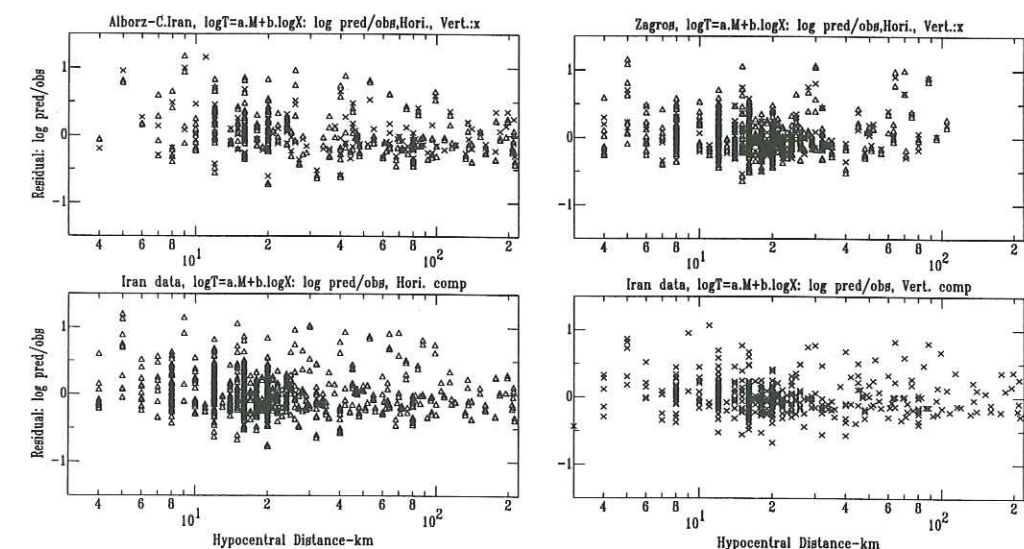


FIG. 5.13 – The residual of the predicted duration values (obtained by relationship 5.8), against hypocentral distances, in Alborz-Central Iran, Zagros and entire of the data base; the horizontal and vertical components are determined. triangles for horizontal and crosses for vertical components

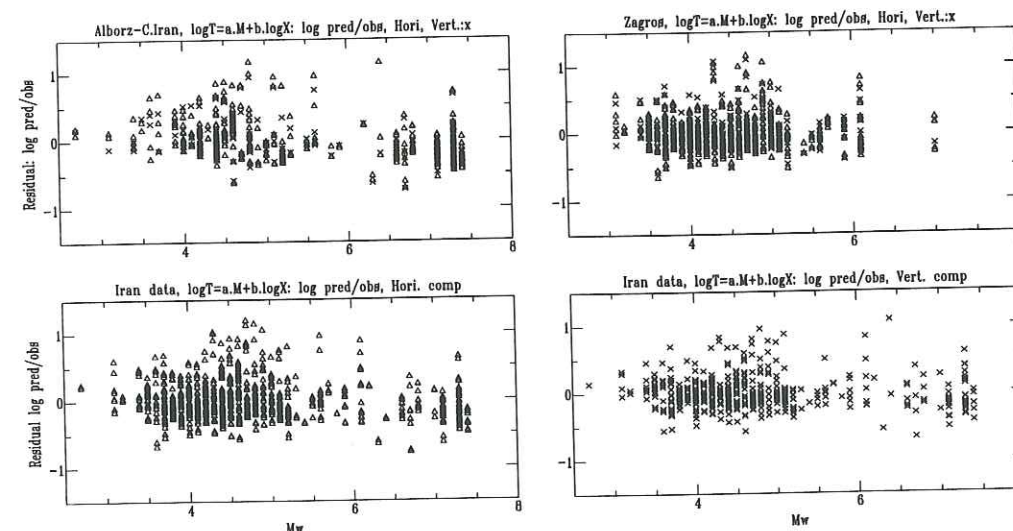


FIG. 5.14 – The residual of the predicted duration values (obtained by relationship 5.8), against M_w , in Alborz-Central Iran, Zagros and entire of the data base; the horizontal and vertical components are determined. (triangles for horizontal and crosses for vertical components)

As it can be seen in Figure 5.10, the distribution of the duration values against 'distances' are not similar in Zagros and Alborz-Central Iran areas; most of the data in the former area are found at short distances (0 to 50 km). This difference comes from the occurrence of the higher magnitude data in Alborz-Central Iran region. Most of the Alborz-Central Iran data are recorded using the analog, Kinematics SMA-1 instruments, in which the sensibility of the triggering is obviously lower than that of the digital SSA-2 recorders (the instruments that have recorded most of the Zagros data). Hence, it seems that the duration of the strong motions in Alborz-Central Iran area might be systematically under-estimated; because most of the Zagros records are triggered with weaker motions and maybe the instrument have started sooner and stopped later than that might be found with a analog instrument. Therefore, the same regression for relationship (5.8) has been repeated on Alborz-Central Iran data, using only data obtained within 50km, which are representative for the damaging earthquakes (Figure 5.15). The results are shown in Table 5.5;

Table 5.5: Result of the regression for relationship (5.8) for the first 50km (Hypo. Distance)

Region/comp.	a	b	R(Coef. Corr.)	Sigma
Central Iran, Alborz (Vert.)	0.103	0.216	0.505	0.300
Central Iran, Alborz (Hori.)	0.097	0.145	0.392	0.363
Zagros (Vertical comp.)	0.009	0.590	0.489	0.202
Zagros (Horizontal comp.)	0.013	0.536	0.416	0.227
Iranian data (Vertical)	0.010	0.512	0.682	0.234
Iranian data (Horizontal)	0.011	0.552	0.697	0.285

These results indicate slightly lower standard deviation for Zagros and entire of the data-base, while the coefficient of correlation decreasing for all regions, in comparison with the values in table 5.4 (for all distances). The residuals of $\log T_0$ for the predictions in the first 50km are shown in Figures 5.16 and 5.17.

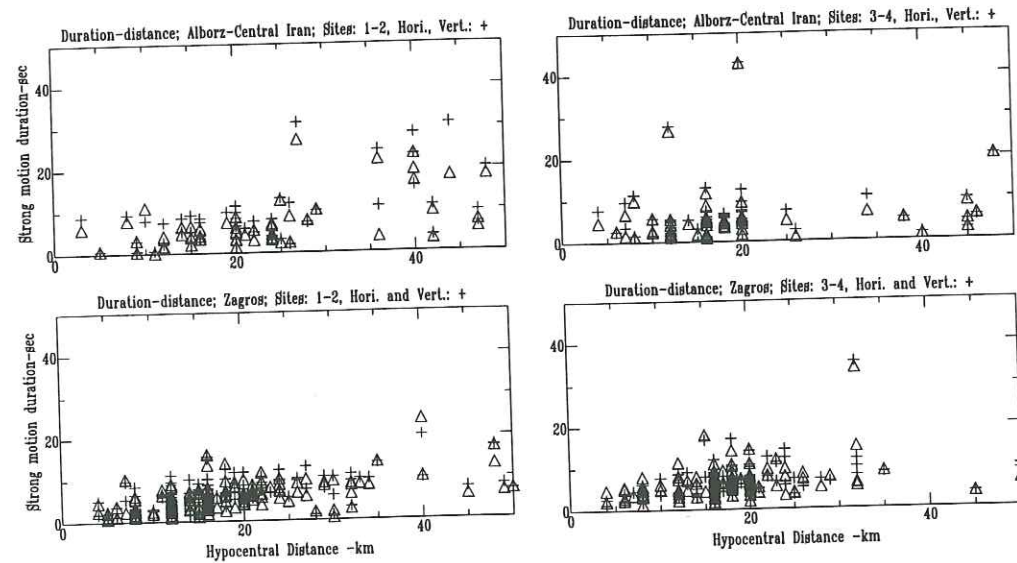


FIG. 5.15 – Distribution of duration values against the hypocentral distances (below 50km) for two areas in Iran. (triangles for horizontal and crosses for vertical components)

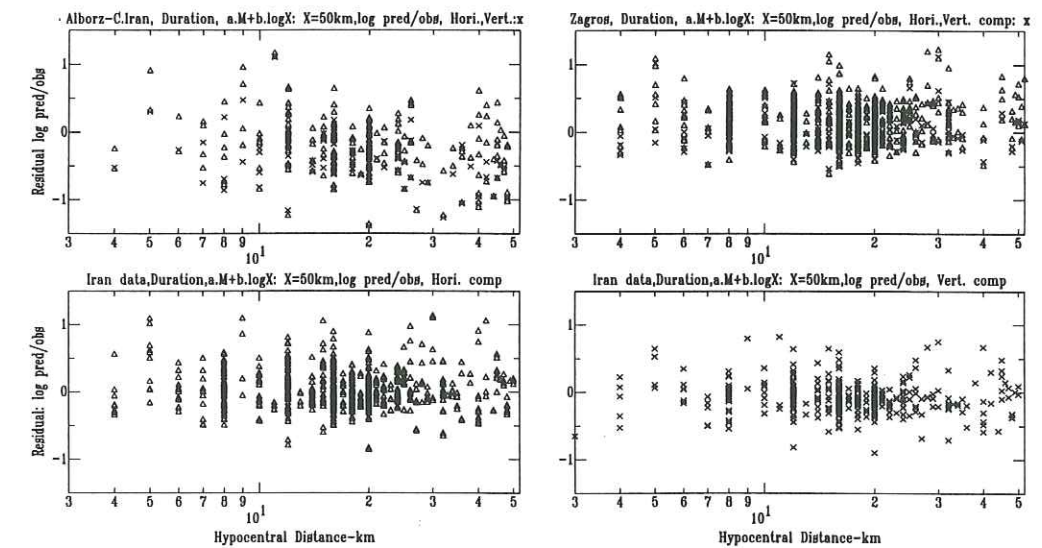


FIG. 5.16 – Residual of the predicted duration values (obtained by relationship (5.8) for first 50km distances), against hypocentral distances, in Alborz-Central Iran, Zagros and entire of the data base; the horizontal and vertical components are considered. (triangles for horizontal and crosses for vertical components)

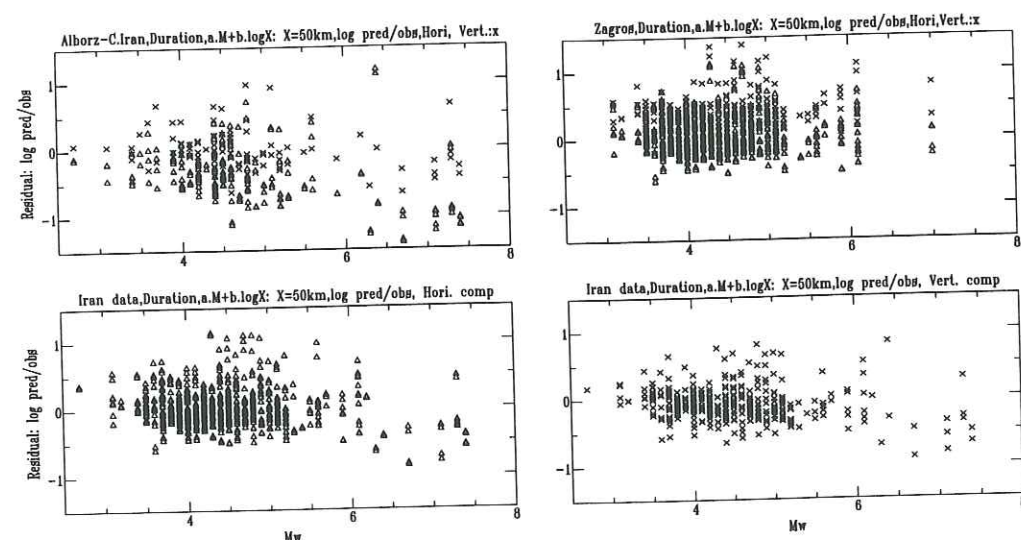


FIG. 5.17 – The residual of the predicted duration values (obtained by relationship (5.8) for first 50km distances), against M_w , in Alborz-Central Iran, Zagros and entire of the data base; the horizontal and vertical components are determined. (triangles for horizontal and crosses for vertical components)

Duration - energy relationship

The relationship between the duration (measured with the 95% interval) are plotted against the ratio of $\frac{e_a}{a_{max}^2}$ in Figures 5.18 to 5.20. The data for all sites are separated for Zagros and Alborz-Central Iran in Figure 5.18.

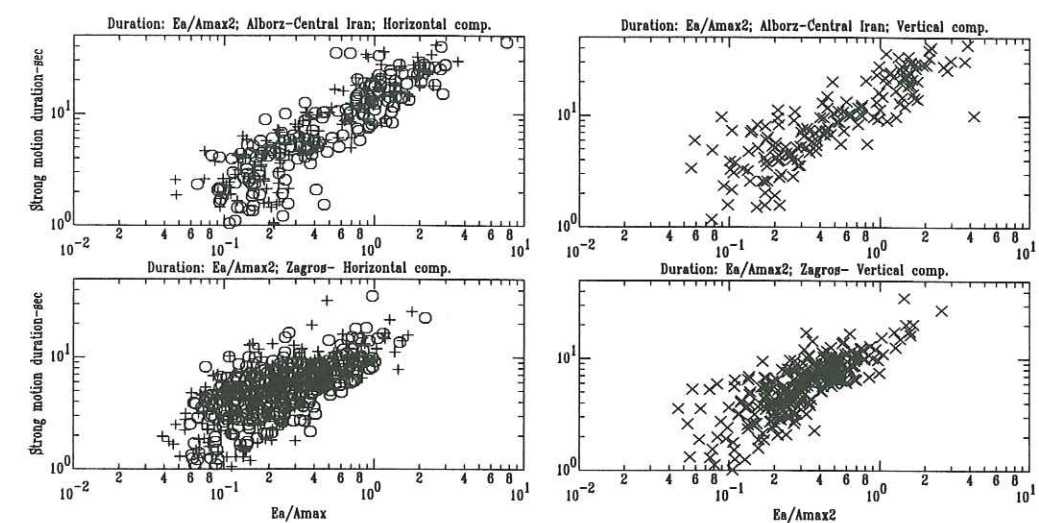


FIG. 5.18 – Strong motion duration, against $\frac{e_a}{a_{max}^2}$ for two areas in Iran. (two horizontal components; left, and the vertical component; right, Alborz-Central Iran; top, Zagros; bottom, are distinguished)

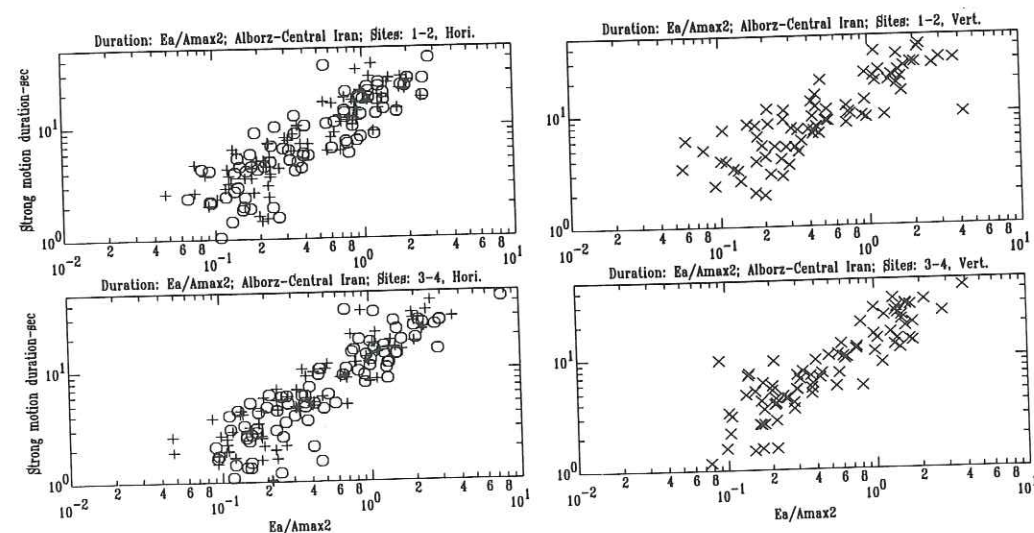


FIG. 5.19 – Strong motion duration, against $\frac{e_a}{a_{max}^2}$ for two site groups, in Central Iran, Alborz area. (two horizontal components; left, and the vertical component; right, site group 1; top, site group 2; bottom, are distinguished)

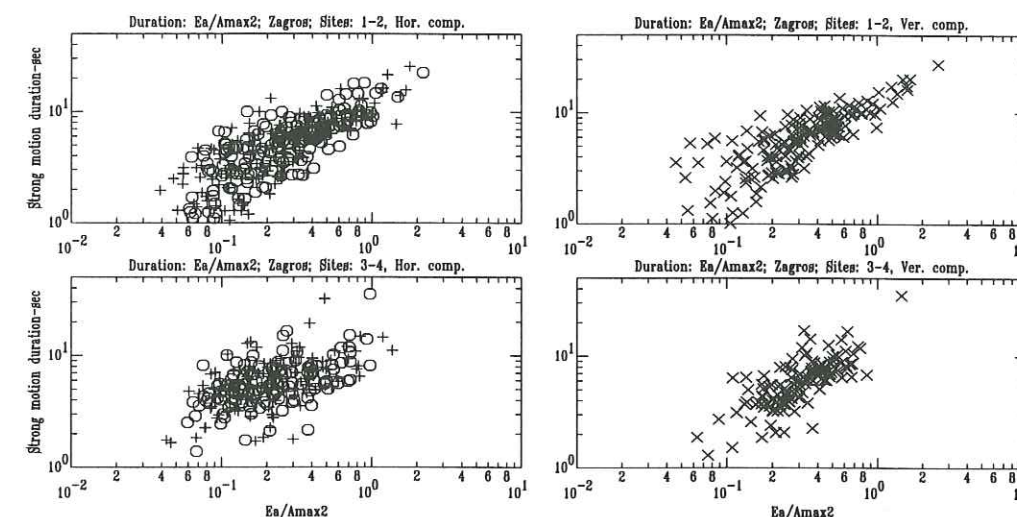


FIG. 5.20 – Strong motion duration, against $\frac{e_a}{a_{max}^2}$ for two site groups, in Zagros area. (two horizontal components; left, and the vertical component; right, are distinguished)

To establish empirical relationships for the duration, the dependence of the duration is first studied as a function of $\frac{e_a}{a_{max}^2}$, as well as the M_w and hypocentral distances. In all of established relationships, it is tried to find the formula with the best fit to the data. It must be mentioned that since no systematic important difference in view point of the site effect was found on the other parameters discussed here, the site factor is eliminated from our duration relationships.

In the following empirical relationships, the interval of 5%-95% is used to establish the empirical relationships.

The relationship 5.3 may be written as;

$$T_0 = A \cdot \left(\frac{e_a}{a_{max}^2} \right)^b$$

and taking the logarithm of the two sides of this relationship, we have;

$$\log T_0 = a + b \cdot \log \left(\frac{e_a}{a_{max}^2} \right) + \sigma \cdot P \quad (5.9)$$

σ is the standard deviation.

Using a one-step method, the regression is done in order to find the parameters a and b for the average of the horizontal components and the vertical component and for Zagros, Alborz-

Central Iran and entire of the data-base. For all of the regressions the correlation coefficient and the standard deviation are presented as well. The results for relationship 5.9, are shown in Table 5.6:

Table 5.6: Result of the regression for relationship 5.9				
Region/comp.	a	b	R(Coef. Corr.)	Sigma
Central Iran, Alborz (Vert.)	1.165	0.746	0.827	0.204
Central Iran, Alborz (Hori.)	1.135	0.873	0.858	0.194
Zagros (Vertical comp.)	1.108	0.689	0.811	0.157
Zagros (Horizontal comp.)	1.078	0.603	0.703	0.186
Iranian data (Vertical)	1.140	0.730	0.843	0.176
Iranian data (Horizontal)	1.120	0.713	0.841	0.199

5.4.3 Attenuation of a_{rms} and e_a

The empirical attenuation relationships for a_{rms} and the energy of acceleration (e_a) are similarly obtained, applying a two-step regression, using the magnitude, distance and the site factors as the dependent variables. The method to establish such relationships for Iran was followed essentially after Joyner and Boore (1981) and Fukushima and Tanaka (1990). This method is used to fit a model to multiple independent variables (magnitude, distance, site,...). Hence, using this method, it is possible to do the regression for the dependence to magnitude and the dependence to distance, as well as the dependence to other terms, separately. In this method the parameters controlling distance and site effects dependence and a set of the amplitude factors, one for each event, must be determined in the first step, by maximizing the likelihood of the set of the observation. The determination of the parameters controlling the magnitude dependence is then performed in a second step, by maximizing the likelihood of the set of the amplitude factors (Joyner and Boore 1993). The applied formula is:

$$\log A = a \cdot M_w + b \cdot X - d \cdot \log X + c_i \cdot S_i + \sigma \cdot P \quad (5.10)$$

where A is the strong motion parameter, a is the coefficient for moment magnitude; M_w , b is a coefficient related to anelastic attenuation, c_i is a constant which related to 4 site classes (Zaré et al 1999a), S_i . The d coefficient for the $\log X$ term correspond to the geometrical expansion. This coefficient is fixed to 1 and 0.5 corresponding to pure body and surface waves, respectively.

The coefficients of the regression using the relationship 5.10 are presented in tables 5.7 and 5.8 for a_{rms} and e_a , respectively.

Table 5.7: The regression coefficients for a_{rms} , applying equation (5.10), with $d=1$.

Region/comp.	a	b	c1	c2	c3	c4	Sigma
Central Iran, Alborz (Vert.)	0.367	0.0008	-1.836	-1.821	-1.819	-1.785	0.328
Central Iran, Alborz (Hori.)	0.383	0.0010	-1.713	-1.610	-1.677	-1.727	0.350
Zagros (Vertical comp.)	0.438	-0.0036	-2.077	-2.116	-2.022	-1.997	0.352
Zagros (Horizontal comp.)	0.458	-0.0015	-1.992	-1.962	-1.971	-2.034	0.341
Iranian data (Vertical)	0.324	0.0010	-1.553	-1.420	-1.642	-1.514	0.350
Iranian data (Horizontal)	0.317	0.0011	-1.350	-1.081	-1.333	-1.244	0.401

Table 5.8: Regression coefficients for e_a , applying equation (5.10), with $d=1$

Region/comp.	a	b	c1	c2	c3	c4	Sigma
Central Iran, Alborz (Vert.)	0.848	-0.0040	-4.509	-4.501	-4.480	-4.359	0.572
Central Iran, Alborz (Hori.)	0.881	-0.0037	-4.353	-4.176	-4.236	-3.286	0.582
Zagros (Vertical comp.)	0.953	-0.0159	-4.777	-4.808	-4.643	-4.556	0.617
Zagros (Horizontal comp.)	0.982	-0.0113	-4.655	-4.543	-4.488	-4.635	0.586
Iranian data (Vertical)	0.802	-0.0036	-4.134	-4.093	-4.370	-4.069	0.591
Iranian data (Horizontal)	0.815	-0.0035	-3.963	-3.678	-3.986	-3.725	0.628

As it is evident from the $c1$ to $c4$ coefficients in tables 5.7 and 5.8, the site effects were not very important in these regressions. The attenuation of the estimated values using (5.10) with the coefficients of tables 5.7, estimated for magnitudes of 5, 6 and 7 events on the rock sites are shown in Figures 5.21 to 5.23, for Alborz-Central Iran, Zagros and entire of the data-base, respectively. The results show that taking $d=1$ (body waves attenuation) induce greater estimations for the near-source distances (less than 20km). Using $d=0.5$ (surface waves attenuation), larger values are obtained at distances more than 60km, for the Alborz-Central Iran and entire of the data-base; Figures 5.21 and 5.23). According to the lesser data for the greater distances and a conservative approach for the near field distance, it is suggested to use the coefficients with $d=1$ for e_a and a_{rms} . However special studies are recommended for the near-field of the large magnitude events, using a deterministic approach on the records obtained in similar conditions.

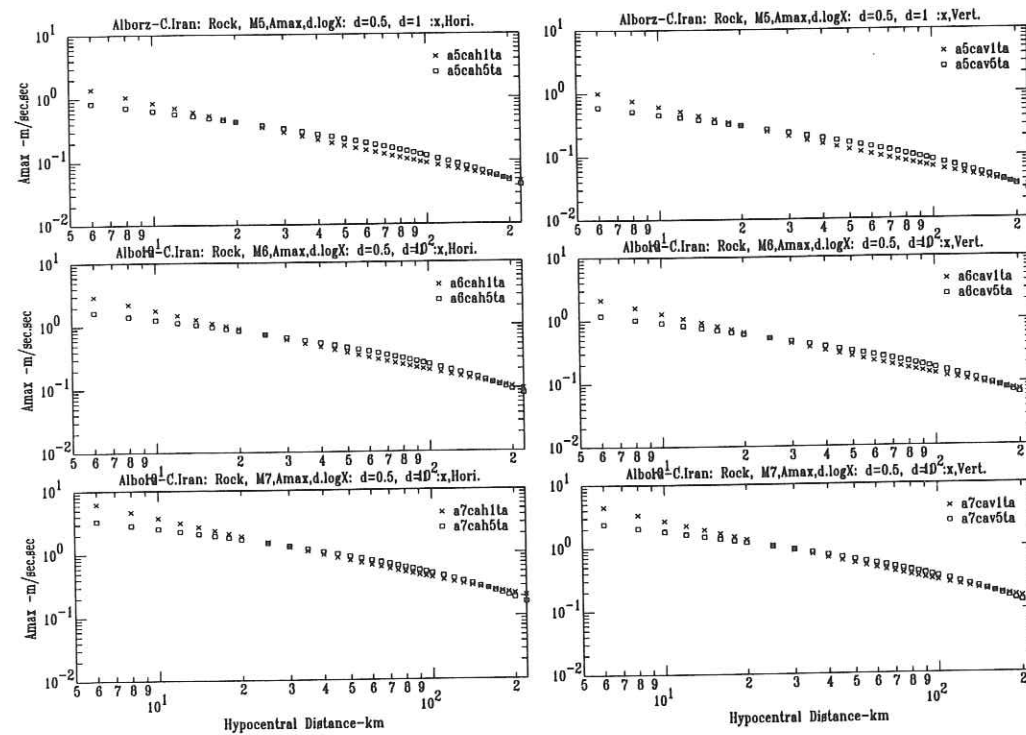


FIG. 5.21 – Attenuation of a_{rms} with distance for magnitudes 5, 6 and 7, using Alborz-Central Iran data. The results are presented for different d values (quadrangles for $d=0.5$, and crosses for $d=1.0$); horizontal component, left; vertical component, right

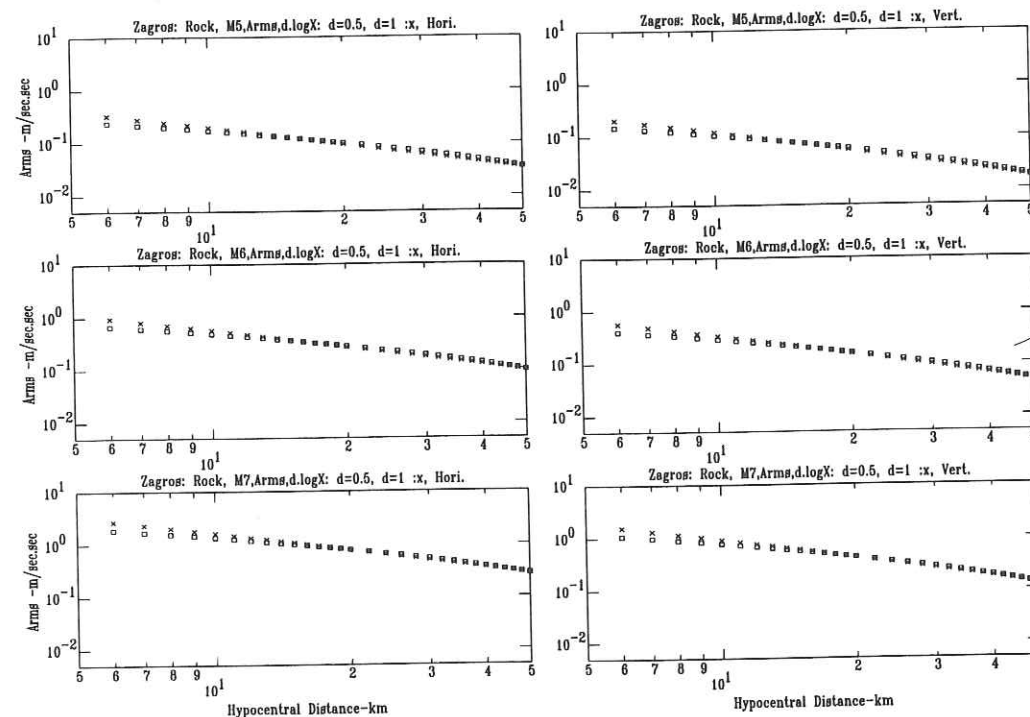


FIG. 5.22 – Attenuation of a_{rms} with distance for magnitudes 5, 6 and 7, using Zagros data. The results are presented for different d values. (quadrangles for $d=0.5$, and crosses for $d=1.0$); horizontal component, left; vertical component, right

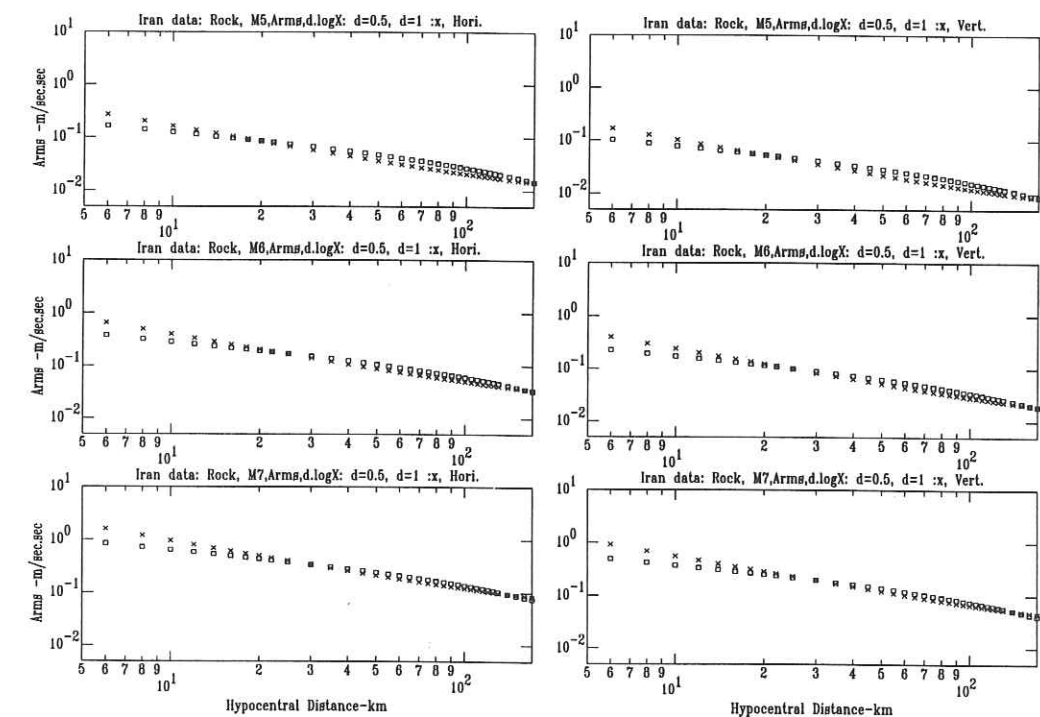


FIG. 5.23 – Attenuation of a_{rms} with distance for magnitudes 5, 6 and 7, using Iranian data-base. The results are presented for different d values (quadrangles for $d=0.5$, and crosses for $d=1.0$); horizontal component, left; vertical component, right

5.5 Conclusions

This article presented investigations on the energy content and the duration values on the Iranian strong motion data. The duration has been calculated using the cumulative integral of the acceleration values. All results are detailed in Appendix 5.1. The conclusions and the propositions for the further studies may be summarized as follows;

- The content of energy of the strong motions is different in Zagros area and the rest of the country). This difference comes partially from the difference in the seismicity rates in Zagros belt, or other reasons (comparing Figures 5.19 and 5.20).

- The Alborz-Central Iran region which represent the seismicity with greater earthquakes recorded in larger distances, shows higher duration.

- According to the distribution of the data which are sub-grouped to Zagros and Alborz-Central Iran groups, and since two probable trends may be assumed in Zagros data, more sophisticated studies may be carried out using higher quality data. Such studies may be followed using the local accelerograph networks to be installed in the high seismic zones (for instance the zones such as Firouzabad, Fin in north Bandarabbas, Lar in southern Fars province or Borazjan in the Bushehr province; Figure 5.1).

- No important influence of site conditions would be detected on duration values. It might come from 95% interval choice.

- The attenuation of a_{rms} and e_a show some differences in the estimations in the near and far source distances. The limits for the application of such relationship must be considered in the future: the attenuation coefficients for the Zagros area give proper results in the distances less than 50km, and for the Alborz-Central Iran region in the distances less than 200km. The entire of the data-base might be used in distances up to 170km. The magnitude limits are the $M_w 3.0$ to $M_w 7.4$ for Alborz-Central Iran and $M_w 3.0$ to $M_w 7.0$ for Zagros region.

Acknowledgement

The BHRC (Building and Housing Research Center, Tehran) which have released the raw strong motion records, is greatly thanked. A financial support in France (for the first author) was provided by a French scholarship (Ministère Français des Affaires Etrangères) is duly acknowledged. The financial support in Iran was provided by IIEES (International Institute of Earthquake Engineering and Seismology), which is thanked.

Appendix 5.1: The database of the duration/energy content study, developed for the Iranian strong motion and applied in this paper.

No	Record	Station	Site	Date	Mw	R	Dur (H1)	Dur (V)	Dur (H2)	Arms (H1)	Arms (V)	Arms (H2)	Ea (H1)	Ea (V)	Ea (H2)
						km	sec	sec	sec	m/s.s	m/s.s	m/s.s	m2/s3	m2/s3	m2/s3
1	1012	Kiasar	2	05/11/74	4.5	64	1.53	5.22	1.56	1.400	0.320	1.200	7.8	1.06	1.700
2	1006-1	Bandarabbas	2	07/03/75	6.1	48	15.04	20.25	11.38	2.300	1.100	3.300	7.10	13.76	5.82
3	1006-2	Bandarabbas	2	07/03/75	5.2	40	16.33	16.27	14.43	0.430	0.370	0.530	11.39	12.68	8.73
4	1007	Minab	1	07/03/75	6.1	80	16.02	17.51	18.23	0.410	0.260	0.350	10.35	11.39	10.81
5	1008	Gheshm Island	1	07/03/75	6.1	56	25.60	20.13	22.57	0.370	0.360	0.360	17.61	16.73	0.400
6	1013	Tonkabon	4	13/03/75	4.4	34	5.83	10.53	7.72	0.890	0.210	0.630	2.13	4.97	4.04
7	1009	Minab	1	12/04/75	4.8	48	11.19	17.34	14.70	0.660	0.200	0.390	2.42	8.94	6.58
8	1026	Shiraz	4	02/06/75	4.1	60	3.64	3.78	6.71	0.900	0.610	1.100	1.600	2.300	1.500
9	1014-4	Hajjabad	3	08/10/75	5.4	32	14.53	11.88	15.17	1.800	1.100	1.600	7.27	4.86	7.82
10	1024	Maraveh-Tappeh	3	27/12/75	4.6	6	2.76	2.56	2.63	1.400	0.370	0.800	6.5	1.49	6.5
11	1034-1	Maku	2	27/02/76	3.9	26	2.38	1.92	2.35	1.300	0.970	1.300	6.6	5.9	6.8
12	1034-2	Maku	2	02/04/76	4.6	12	6.8	2.58	1.88	1.660	1.900	2.900	2.1	1.76	1.27
13	1040-3	Naghan-1	1	05/09/76	4.7	88	1.28	1.58	1.49	1.200	1.400	1.200	4.2	8.1	6.2
14	1043	Ghaen	1	07/11/76	6.4	10	11.20	7.82	10.58	3.100	3.900	3.500	3.48	3.02	2.94
15	1047-8	Vendik	2	07/11/76	6.4	11	1.1	6.0	1.3	2.800	4.200	2.200	0.5	5.1	0.7
16	1047-1	Vendik	2	07/11/76	4.8	9	3.0	5.5	5.2	5.800	2.200	4.900	0.5	5.0	4.5
17	1047-10	Vendik	2	09/11/76	5.1	5	6.6	5.8	7.1	2.100	2.500	2.500	5.8	1.0	4.8
18	1047-1	Maku	2	24/11/76	7.3	48	16.07	20.10	20.40	1.600	0.690	1.300	6.56	9.43	8.81
19	1046-2	Maku	2	24/11/76	5.5	47	7.61	9.57	7.02	1.400	0.430	1.300	3.99	4.76	3.94
20	1049-1	Siah-Cheshmeh	1	06/12/76	4.4	3	7.05	9.72	7.38	0.880	0.530	1.000	3.14	6.46	4.36
21	1049-2	Siah-Cheshmeh	1	06/12/76	4.4	19	6.10	8.74	5.78	0.350	0.190	0.580	3.06	4.46	0.430
22	1049-3	Siah-Cheshmeh	1	12/12/76	4.8	14	6.11	8.35	6.42	0.260	0.150	0.380	3.70	5.03	4.54
23	1050-1	Bandarabbas	2	21/03/77	7.0	52	21.56	27.32	17.98	2.200	1.100	3.000	11.40	17.09	8.86
24	1052	Gheshm-Island	1	21/03/77	7.0	71	7.75	7.44	7.55	0.750	0.520	0.740	6.04	5.07	7.21
25	1054-1	Naghan-1	1	06/04/77	6.1	7	2.78	3.18	2.70	2.500	1.600	1.900	1.06	1.20	1.12
26	1055	Farsan	1	06/04/77	6.1	32	14.00	12.59	13.59	0.490	0.280	0.560	9.38	7.32	7.41
27	1058	Dastgerd	2	06/04/77	6.1	18	3.95	5.08	4.16	2.300	1.300	2.300	1.32	2.31	2.02
28	1059	Ardal	4	06/04/77	6.1	21	1.62	5.32	3.02	1.800	0.480	1.300	5.6	2.00	1.08
29	1056-5	Naghan-1	1	12/04/77	4.9	15	4.4	2.41	1.75	1.800	0.420	0.790	1.1	3.5	3.2
30	1060-2	Naghan-1	1	04/05/77	4.8	20	3.21	2.64	5.02	0.340	0.510	0.310	8.7	9.8	1.31
31	1080-8	Naghan-1	1	21/10/77	5.0	19	3.39	5.24	3.06	2.200	1.600	2.900	1.57	2.23	1.99
32	1092-1	Aghajari	2	31/03/78	4.4	30	2.56	5.90	1.70	0.700	0.210	1.200	6.6	1.56	1.6
33	1080-10	Naghan-1	1	12/04/78	4.9	15	1.19	1.01	9.6	2.400	3.100	3.300	40	3.9	3.8
34	1080-11	Naghan-1	1	20/05/78	5.0	28	1.39	1.32	2.64	1.100	1.100	0.670	3.1	2.5	5.7
35	1080-12	Naghan-1	1	11/08/78	4.3	30	5.6	1.12	5.3	2.800	1.100	2.800	1.3	8.4	0.6
36	1094-1	Kazerun	2	29/09/78	4.9	12	7.63	7.05	4.71	0.840	0.390	1.700	2.36	3.18	2.03
37	1082-1	Deyhuk	1	16/09/78	7.4	36	34.01	30.20	34.91	4.900	3.600	5.000	9.03	10.51	9.76
38	1083-1	Boshruyeh	1	16/09/78	7.4	64	21.58	24.34	22.56	1.700	2.100	2.600	15.04	16.58	14.12
39	1084-1	Tabas	3	16/09/78	7.4	27	16.56	14.88	18.30	2.900	1.400	1.800	7.98	10.36	8.46
40	1086	Bajestan	3	16/09/78	7.4	140	27.64	31.10	26.36	1.500	0.470	1.500	21.30	24.58	21.47
41	1090-2	Kashmar	3	16/09/78	7.4	234	29.66	25.52	27.62	1.100	0.780	1.200	18.58	18.22	16.29
42	1082-6	Deyhuk	1	17/09/78	4.7	53	9.7	2.34	1.04	1.700	0.740	1.300	1.8	1.34	3.4
43	1103-1	Tabas	1	24/09/78	4.5	22	3.59	4.88	2.39	0.560	0.360	0.890	1.43	1.54	6.2
44	1104-2	Deyhuk	1	24/09/78	4.5	42	7.6	3.79	5.26	1.700	0.450	0.550	1.8	7.7	3.5
45	1093-2	Khonj	1	12/10/78	4.2	75	3.69	4.67	4.30	0.570	0.480	0.660	1.45	1.30	1.74
46	1103-3	Tabas	1	12/10/78	4.9	20	3.50	8.28	2.67	1.400	0.530	2.200	6.7	3.38	4.2
47	1098-3	Talesh	3	04/11/78	6.2	20	4.38	5.42	4.20	1.100	0.720	1.100	0.6	3.09	1.00
48	1096-1	Naghan-1	1	14/12/78	6.1	5	5.7	7.8	8.8	2.600	2.500	2.600	23	3.1	4.0
49	1096-2	Naghan-1	1	14/12/78	4.7	5	1.87	1.98	2.6	0.480	0.440	0.300	3.1	2.1	1.2
50	1097-2	Naghan-2	1	14/12/78	4.7	5	2.2	7.5	3.91	3.300	1.300	0.430	1.1	1.9	3.3
51	1103-9	Tabas	1	26/12/78	4.5	21	4.42	5.86	4.24	0.590	0.410	1.100	1.35	1.87	2.0
52	1102	Bajestan	3	16/01/79	6.8	135	7.88	10.32	10.43	1.300	0.350	0.930	4.39	5.14	5.11
53	1106	Sedeh	3	16/01/79	6.8	80	17.33	13.34	15.20	0.820	0.770	1.000	11.70	8.18	9.74
54	1107	Khazri	1	16/01/79	6.8	61	13.59	18.51	13.16	0.680	0.450	0.820	8.45	12.36	8.16
55	1109	Gonabad	4	16/01/79	6.8	86	15.98	20.62	12.30	0.360	0.860	0.920	13.11	5.80	0.700
56	1113	Khaf	2	16/01/79	6.8	80	11.85	21.73	13.86	1.800	0.640	1.500	8.19	15.15	8.86
57	1103-11	Tabas	1	17/01/79	5.1	16	6.10	7.43	5.52	1.200	1.000	2.000	2.23	2.47	1.83
58	1103-12	Tabas	1	13/02/79	5.5	55	10.01	11.30	9.94	1.100	0.760	1.300	7.16	8.10	7.27
59	1125-2	Aghajari	2	26/03/79	5.1	25	3.14	3.20	1.44	1.100	0.920	2.200	9.2	1.02	4.4
60	1117	Sedeh	3	14/11/79	6.6	96	20.90	25.88	23.09	0.510	0.270	0.510	14.55	13.67	13.73
61	1118	Ghaen	1	14/11/79	6.6	55	11.28	10.35	10.05	0.790	0.800	1.200	6.29	5.97	5.03
62	1121	Khaf	2	14/11/79	6.6	72	16.91	21.67	17.17	1.800	0.910	1.900	10.36	13.97	9.80
63	1124	Roshkhar	1	14/11/79	6.6	116	14.40	21.11	17.11	0.470	0.330	0.380	7.86	14.60	10.58
64	1130-2	Kashmar	3	14/11/79	6.6	184	13.18	14.40	14.15	0.660	0.390	0.740	7.46	7.28	9.23
65	1132-1	Ferdows	1	14/11/79	6.6	132	25.45	28.40	23.03	0.660	0.410	0.800	19.41	20.48	15.59
66	1143-1	Khaf	2	23/11/79	5.0	69	10.84	10.01	10.93	0.450	0.270	0.490	6.26	5.18	7.07
67	1131	Torbat-Heydarieh	3	27/11/79	7.1	160	23.89	29.51	25.14	1.400	0.630	1.200	15.61	20.41	16.61
68	1134-2	Bajestan	3	27/11/79	7.1	152	12.26	12.12	12.92	2.900	0.900	2.700	7.62	15.51	7.89
69	1135	Kahk	1	27/11/79	7.1	88	17.68	19.84	19.78	1.200	0.710	0.780	11.12	12.97	13.06
70	1137	Birjand	1	27/11/79	7.1	136	17.84	30.66	18.35	0.980	0.400	0.850	11.99	23.97	12.97
71	1138-1	Sedeh	3	27/11/79	7.1	80	20.86	24.51	20.52	1.700	0.730	1.700	15.72	16.79	13.89
72	1139	Ghaen	1	27/11/79	7.1	44	11.44	16.16	13.70	4.000	2.800	3.300	6.30	10.66	8.71
73	1140-1	Khazri	1	27/11/79	7.1	80	14.84	21.73	15.44	1.900	1.300	1.900	9.38	12.03	7.88
74	1141-1	Theybad	4	27/11/79	7.1	120	27.44	38.47	26.20	1.900	0.800	2.000	16.23	26.57	17.20
75	1142-1	Gonabad	4	27/11/79	7.1	92	17.30	23.74	17.82	1.700	1.300	2.000	8.76	13.92	7.61
76	1143-2	Khaf	2	27/11/79	7.1	64	27.11	29.26	27.56	3.300	1.800	3.300	18.72	19.76	19.79
77	1143-3	Khaf	2	27/11/79	4.6	40	17.08	19.51	17.77	0.740	0.420	0.730	9.58	11.63	10.31
78	1144-2	Roshkhar	1	27/11/79	7.1	108	24.35	28.41	22.42	0.930	0.970	1.100	15.10	19.97	11.84
79	1145	Torbat-Jam	2	27/11/79	7.1	160	14.35	27.64	13.34	1.000	0.540	1.100	12.90	24.14	11.40
80	1143-4	Khaf	2	28/11/79	4.7	29	10.19	10.03	10.19	1.200	1.300	1.200	2.86	5.43	4.14

No	Record	Station	Site	Date	Mw	R km	Dur (H1) sec 5-95	Dur (V) sec 5-95	Dur (H2) sec 5-95	Arms (H1) m/s.s 5-95	Arms (V) m/s.s 5-95	Arms (H2) m/s.s 5-95	dur (H1) sec 5-75	dur (V) sec 5-75	dur (H2) sec 5-75	Arms (H1) m/s.s 5-75	Arms (V) m/s.s 5-75	Arms (H2) m/s.s 5-75	Ea (H1) m2/s3	Ea (V) m2/s3	Ea (H2) m2/s3
180	1500-3	Zanjiran	2	14/03/94	4.3	8	3.15	4.05	2.67	1.600	0.740	2.100	1.54	2.04	1.09	2.100	0.930	2.900	0.0950	0.250	1.300
181	1492-2	Zarrat	1	17/03/94	4.8	34	7.42	9.80	9.26	0.650	0.290	0.560	3.86	5.15	4.05	0.800	0.350	0.750	0.0350	0.092	0.320
182	1500-4	Zanjiran	2	17/03/94	4.8	12	6.02	6.33	5.08	1.600	0.810	1.700	1.88	2.34	1.32	2.600	1.200	2.900	0.1800	0.460	1.600
183	1492-3	Zarrat	1	17/03/94	4.6	16	6.67	6.33	5.61	0.450	0.220	0.550	3.60	3.42	2.44	0.540	0.260	0.730	0.150	0.033	0.190
184	1494-2	Kavar	2	17/03/94	4.8	20	8.64	11.06	9.34	0.470	0.310	0.420	3.95	4.84	5.53	0.620	0.410	0.480	0.220	0.120	0.180
185	1494-3	Kavar	2	17/03/94	4.6	12	3.53	4.15	3.09	1.400	0.790	1.600	1.31	2.10	1.64	2.000	0.980	2.000	0.790	0.290	0.910
186	1500-5	Zanjiran	2	17/03/94	4.2	16	3.01	4.18	4.08	2.100	0.760	1.400	1.88	2.50	2.45	2.400	0.860	1.600	1.500	0.270	0.0930
187	1492-4	Zarrat	1	18/03/94	4.4	21	6.20	7.32	6.02	1.100	0.560	1.200	3.10	4.24	1.76	1.400	0.650	1.900	0.850	0.260	0.0890
188	1494-4	Kavar	2	18/03/94	4.4	11	6.72	5.95	5.98	0.840	0.650	0.940	3.19	2.68	2.14	1.100	0.850	1.100	0.992	0.057	0.120
189	1500-6	Zanjiran	2	18/03/94	4.4	11	6.72	5.95	5.98	0.840	0.650	0.940	3.19	2.68	2.14	1.100	0.850	1.100	0.992	0.057	0.120
190	1500-7	Zanjiran	2	18/03/94	3.5	8	2.59	3.13	2.31	0.290	0.170	0.480	1.14	1.63	1.81	0.390	0.200	0.710	0.024	0.010	0.058
191	1500-8	Zanjiran	2	19/03/94	4.4	11	7.59	6.72	7.73	0.780	0.590	0.760	3.61	2.79	2.98	1.000	0.800	1.100	0.520	0.260	0.500
192	1500-9	Zanjiran	2	19/03/94	3.1	12	3.27	4.32	3.10	0.320	0.160	0.360	0.95	2.14	1.16	0.520	0.200	0.520	0.037	0.013	0.045
193	1500-10	Zanjiran	2	20/03/94	4.3	12	3.53	3.69	2.07	0.690	0.370	1.000	1.75	2.35	6.3	0.870	0.410	1.600	0.190	0.057	0.240
194	1500-11	Zanjiran	2	20/03/94	4.0	12	7.15	5.43	5.29	0.280	0.270	0.370	3.37	2.57	2.23	0.360	0.350	0.500	0.063	0.045	0.079
195	1500-12	Zanjiran	2	21/03/94	3.8	8	3.22	3.34	3.37	0.710	0.410	0.640	71	1.71	1.00	1.300	0.510	1.000	0.180	0.063	0.150
196	1492-5	Zarrat	1	23/03/94	4.7	20	6.32	6.63	5.61	1.000	0.450	1.300	2.11	3.44	1.63	1.600	0.550	2.100	0.720	0.150	1.100
197	1500-13	Zanjiran	2	23/03/94	4.7	8	7.12	9.78	7.00	5.300	1.600	5.800	2.15	4.80	2.64	8.500	2.100	8.400	2.2000	2.900	0.730
198	1492-6	Zarrat	1	30/03/94	5.2	24	10.89	12.16	9.10	1.200	0.670	1.500	1.62	1.97	1.04	1.300	0.740	2.200	0.900	0.447	0.280
199	1492-7	Zarrat	1	01/04/94	4.6	32	9.93	10.98	7.82	0.410	0.200	0.570	4.62	6.00	4.03	0.530	0.230	0.700	0.180	0.047	0.280
200	1492-8	Zarrat	1	03/04/94	5.2	24	10.89	12.16	9.10	1.200	0.670	1.500	1.62	1.97	1.04	1.300	0.740	2.200	0.900	0.447	0.280
201	1492-9	Zarrat	1	03/04/94	4.7	26	8.95	10.05	8.99	0.580	0.280	0.580	5.10	4.98	7.43	1.600	0.630	2.000	1.800	0.420	0.400
202	1492-10	Zarrat	1	12/04/94	3.4	14	1.42	1.54	4.75	0.490	0.140	0.072	1.38	1.50	1.33	0.440	0.120	0.120	0.037	0.003	0.003
203	1492-11	Zarrat	1	30/04/94	4.1	23	8.14	6.81	7.85	0.360	0.200	0.340	3.72	4.03	4.07	0.350	0.190	0.660	0.042	0.012	0.058
204	1492-12	Zarrat	1	07/05/94	4.1	16	4.34	6.51	5.28	0.340	0.130	0.280	1.74	3.48	1.92	0.470	0.160	0.410	0.320	0.078	0.230
205	1502-1	Zanjiran	2	25/05/94	4.3	17	5.47	6.25	5.90	0.730	0.340	0.590	2.61	2.73	2.75	0.930	0.450	0.760	0.320	0.078	0.230
206	1502-2	Zanjiran	2	25/05/94	4.3	17	5.47	6.25	5.90	0.730	0.340	0.590	2.61	2.73	2.75	0.930	0.450	0.760	0.320	0.078	0.230
207	1492-13	Zarrat	1	05/06/94	4.8	27	6.35	7.47	5.30	0.800	0.450	1.000	2.57	4.84	2.12	1.100	0.490	1.400	0.450	0.170	0.610
208	1502-4	Zanjiran	2	05/06/94	4.8	10	2.93	3.94	3.45	4.700	1.900	4.700	1.67	1.54	30	0.310	0.210	1.000	0.022	0.010	0.045
209	1502-3	Zanjiran	2	05/06/94	4.8	10	2.93	3.94	3.45	4.700	1.900	4.700	1.67	1.54	30	0.310	0.210	1.000	0.022	0.010	0.045
210	1502-5	Zanjiran	2	06/06/94	4.2	10	2.23	2.83	1.65	1.100	0.510	1.900	1.20	2.03	6.4	1.400	0.500	0.870	0.290	0.130	0.350
211	1492-14	Zarrat	1	11/06/94	4.8	29	9.19	7.67	7.57	0.530	0.300	0.650	3.62	3.53	3.23	0.740	0.500	0.870	0.290	0.130	0.350
212	1502-6	Zanjiran	2	13/06/94	4.8	19	8.10	7.12	8.03	0.850	0.610	0.840	3.26	3.08	3.97	1.200	0.820	1.100	0.090	0.041	0.098
213	1502-7	Zanjiran	2	18/06/94	4.2	20	6.31	6.98	6.25	0.360	0.230	0.380	2.74	3.41	3.24	0.480	0.290	0.480	0.090	0.041	0.098
214	1492-15	Zarrat	1	18/06/94	5.1	21	6.39	9.08	6.80	2.200	0.690	2.100	2.09	3.98	2.33	3.400	0.920	3.200	3.400	0.480	0.340
215	1493-1	Fiروزabad	3	18/06/94	5.1	18	9.61	11.70	10.24	0.290	0.150	0.200	2.33	2.52	2.11	2.600	1.800	3.000	2.200	1.100	2.800
216	1502-8	Zanjiran	2	20/06/94	5.1	8	7.59	6.88	6.31	1.600	1.200	2.000	2.33	2.52	2.11	2.600	1.800	3.000	2.200	1.100	2.800
217	1492-16	Zarrat	1	20/06/94	5.9	29	7.67	11.09	6.17	7.600	2.500	8.500	3.51	5.57	3.85	9.900	3.100	9.500	4.9000	7.400	4.900
218	1493-2	Fiروزabad	3	20/06/94	5.9	17	8.84	10.44	9.26	5.000	2.500	4.100	2.89	4.98	2.32	7.600	3.200	7.200	2.4000	7.400	1.700
219	1495	Maharloo (PTT)	1	20/06/94	5.9	50	15.73	14.96	16.20	0.690	0.350	0.500	7.26	7.34	8.06	0.890	0.440	0.620	0.820	0.210	0.450
220	1498	Bababur	2	20/06/94	5.9	63	12.82	15.46	14.11	0.690	0.370	0.700	8.30	7.62	6.98	0.750	0.470	0.880	0.670	0.240	0.770
221	1502-9	Zanjiran	2	20/06/94	5.9	7	5.46	4.32	5.56	2.500	2.400	2.800	2.68	2.17	2.33	3.2000	2.9000	3.9000	39.000	27.000	50.00
222	1492-17	Zarrat	1	20/06/94	4.5	16	9.58	10.60	9.00	0.380	0.190	0.400	3.83	4.59	3.29	0.520	0.250	0.580	0.150	0.042	0.160
223	1492-18	Zarrat	1	20/06/94	4.5	16	9.58	10.60	9.00	0.380	0.190	0.400	3.83	4.59	3.29	0.520	0.250	0.580	0.150	0.042	0.160
224	1493-3	Fiروزabad	3	20/06/94	4.5	18	10.14	9.68	10.40	0.340	0.230	0.310	4.86	4.49	5.41	0.430	0.300	0.380	0.130	0.059	0.110
225	1492-19	Zarrat	1	21/06/94	4.3	15	7.32	9.10	8.09	0.450	0.180	0.400	2.64	4.01	2.80	0.650	0.240	0.610	0.160	0.034	0.150
226	1492-20	Zarrat	1	21/06/94	4.7	16	7.57	10.11	8.14	0.690	0.220	0.590	3.06	4.75	4.24	0.950	0.290	0.720	0.400	0.057	0.320
227	1493-4	Fiروزabad	3	21/06/94	4.7	18	9.95	10.19	9.31	0.350	0.220	0.320	5.57	6.08	4.65	0.420	0.250	0.400	0.140	0.052	0.110
228	1492-21	Zarrat	1	21/06/94	4.1	18	5.16	5.95	5.53	0.320	0.210	0.370	2.66	3.46	2.46	0.400	0.240	0.490	0.060	0.029	0.084
229	1492-22	Zarrat	1	22/06/94	4.3	15	7.32	7.69	6.41	0.230	0.120	0.270	2.92	3.70	2.32	0.320	0.160	0.400	0.042	0.013	0.053
230	1518-1	Fiروزabad	3	22/06/94	3.1	4	1.33	1.30	3.55	1.100	0.160	0.110	58	1.75	59	0.970	0.180	0.230	0.079	0.004	0.005
231	1501-1	Zanjiran	2	23/06/94	3.7	12	1.05	1.87	80	2.600	1.000	3.300	31	1.38	20	4.300	1.000	5.900	0.800	0.220	0.990
232	1501-2	Zanjiran	2	23/06/94	3.7	12	1.05	1.87	80	2.600	1.000	3.300	31	1.38	20	4.300	1.000	5.900	0.800	0.220	0.990
233	1501-3	Zanjiran	2	23/06/94	3.8	12	4.65	5.98	5.10	0.250	0.140	0.230	1.68	3.00	1.42	0.370	0.250	0.580	0.120	0.031	0.150
234	1492-23	Zarrat	1	24/06/94	4.0	20	6.86	7.73	5.95	0.400	0.190	0.480	3.01	3.95	3.15	0.530	0.240	0.580	0.120	0.031	0.150
235	1501-4	Zanjiran	2	24/06/94	4.0	15	7.03	6.82	6.16	0.290	0.250	0.350	3.27	2.21	2.12	0.370	0.350	0.530	0.066	0.040	0.084
236	1501-5	Zanjiran	2	24/06/94	3.7	8	1.29	2.75	91	0.720	0.240	0.400	60	1.61	1.18	0.920	0.280	0.280	0.074	0.018	0.200
237	1501-6	Zanjiran	2	24/06/9																	

No	Record	Station	Site	Date	Mw	R	Dur (H1)	Dur (H2)	Arms (H1)	Arms (H2)	Arms (H1)	Arms (H2)	Ea (H1)	Ea (H2)	Ea (H1)	Ea (H2)
						km	sec	sec	m/s.s	m/s.s	m/s.s	m/s.s	m2/s3	m2/s3	m2/s3	m2/s3
362	1556	Bandar-Deylam	4	22/04/95	5.1	95	11.09	12.27	0.190	0.042	0.230	8.48	9.08	7.27	0.190	0.043
363	1581	Lendeh	1	22/04/95	5.1	51	11.90	12.43	0.190	0.042	0.230	8.48	9.08	7.27	0.190	0.043
364	1535-2	Rudbar	3	26/04/95	4.8	8	2.49	2.59	2.80	2500	2000	2200	97	1.00	.73	.3600
365	1548	Astaneh	4	26/04/95	4.8	16	8.88	11.30	10.89	0.290	0.130	0.180	3.25	6.74	6.71	.0420
366	1558	Shabankareh	4	02/05/95	3.7	18	6.30	5.38	7.62	.0240	.0210	.0190	1.64	1.97	3.23	.0410
367	1536-2	Ghir	4	03/05/95	4.7	28	5.30	7.12	5.01	.1200	.0660	.1200	2.88	1.99	2.80	.1400
368	1625-1	Ghaleh-Ganj (Kahnoudi)	1	12/05/95	4.0	47	5.02	6.72	6.22	.0420	.0320	.130	3.94	3.74	.0730	.0280
369	1529-1	Lali	3	14/05/95	4.0	18	4.92	6.84	5.24	.0250	.0120	.0290	1.32	3.61	1.49	.0430
370	1621	Darreh-Shahr - Ilam	1	17/05/95	4.5	14	6.38	5.64	7.36	.0480	.0330	.0370	2.58	2.03	3.69	.0660
371	1535-3	Rudbar	3	17/05/95	4.2	12	2.82	3.55	2.92	.0420	.0300	.0330	.63	1.61	.87	.0750
372	1551-1	Shabastar	1	17/05/95	4.0	24	6.35	3.90	6.42	.0340	.0480	.0370	3.00	1.82	3.95	.0430
373	1551-2	Shabastar	1	18/05/95	4.2	22	5.89	3.36	4.17	.0560	.1100	.0810	3.22	1.19	2.97	.0670
374	1546	Tasuj	2	18/05/95	4.4	20	5.01	7.55	5.79	.0330	.0160	.0320	1.10	3.22	1.45	.0620
375	1551-3	Shabastar	1	18/05/95	4.2	24	2.61	4.03	4.08	.0210	.0150	.0150	1.07	2.43	2.16	.0290
376	1594	Khorramabad	2	26/05/95	4.2	20	6.20	6.88	4.61	.0320	.0190	.0380	2.81	3.81	7.9	.0430
377	1543	Namin	3	27/05/95	4.8	82	8.46	9.85	10.29	.0330	.0160	.0320	4.36	5.00	3.70	.0410
378	1590-2	Sisakht	1	27/05/95	4.6	70	9.2	2.35	2.02	.0970	.0560	.0570	.64	1.81	1.50	.1000
379	1633-1	Namin	3	27/05/95	4.8	80	8.47	10.11	10.34	.0330	.0160	.0320	4.37	5.07	3.70	.0410
380	1533-2	Seifabad (S. Kazenun)	1	31/05/95	5.0	20	5.99	8.59	7.34	.0440	.0220	.0390	1.57	3.93	2.70	.0750
381	1552	Pol-e Sefid	4	02/06/95	4.1	18	3.40	6.09	5.15	.0450	.0210	.0300	.37	2.44	.72	.1200
382	1635-1	Pol-e Sefid	4	02/06/95	4.1	18	3.41	6.09	5.16	.0450	.0210	.0300	.37	2.44	.72	.1200
383	1620-1	Doab (Pol-e Sefid)	3	03/06/95	4.0	20	1.91	3.88	1.36	.2600	.1000	.2100	.34	2.78	.56	.5400
384	1576	Gavbandi	3	18/06/95	3.5	12	4.56	3.56	3.46	.0250	.0350	.0390	1.84	1.84	1.57	.0350
385	1626	Hassan-Keif	3	26/06/95	5.1	14	4.34	5.19	4.38	.1100	.0730	.0900	1.10	2.24	.65	.1900
386	1542	Ammarloo	3	10/07/95	3.6	12	.82	1.50	1.50	.0420	.0240	.0280	.32	.78	.73	.0590
387	1635-2	Pol-e Sefid	4	27/07/95	4.0	20	5.34	4.76	5.91	.0230	.0290	.0180	3.06	1.88	3.42	.0270
388	1557	Delvar	2	28/07/95	3.8	20	5.34	6.05	6.36	.0210	.0130	.0150	1.94	2.73	2.62	.0310
389	1620-2	Doab	3	28/07/95	4.1	20	1.88	4.04	1.35	.1400	.0580	.1300	.49	2.54	.59	.2500
390	1620-3	Doab	3	14/08/95	3.7	18	3.11	6.52	5.78	.0330	.0140	.0140	.88	2.85	1.87	.0550
391	1620-4	Doab	3	15/08/95	3.9	18	2.12	5.68	4.70	.0940	.0240	.0290	.62	2.61	1.16	.1500
392	1631-2	Musian	3	16/08/95	3.7	16	6.05	8.30	2.99	.0100	.0077	.0230	2.06	2.91	.38	.0150
393	1569	Mahan	4	04/09/95	4.4	20	4.06	9.52	5.88	.0220	.0069	.0140	.75	3.62	1.26	.0460
394	1549-1	Ammarloo	3	07/09/95	3.7	12	1.95	.89	1.44	.0550	.1000	.1300	.81	.53	.77	.0760
395	1549-2	Ammarloo	3	21/09/95	3.5	12	2.44	2.16	1.64	.0270	.0340	.0370	1.45	1.48	.69	.0310
396	1647-1	Dalin (SE Sepidan-Fars)	2	05/10/95	3.7	12	2.66	2.81	2.63	.1200	.0790	.1200	1.30	1.74	.94	.1500
397	1540	Rasht (Hous.)	3	13/10/95	4.9	16	11.73	12.96	11.52	.0310	.0096	.0330	7.39	7.90	8.57	.0340
398	1637-1	Rasht (Hous.)	3	13/10/95	5.2	16	11.73	12.94	11.51	.0310	.0097	.0330	7.39	7.95	8.57	.0340
399	1537	Sefidrud Dam	1	15/10/95	5.2	25	12.47	13.01	12.53	.0470	.0210	.0170	5.82	4.75	5.13	.0600
400	1541	Rasht (University)	3	15/10/95	5.2	20	9.69	12.47	9.18	.0330	.0150	.0490	3.96	6.58	3.01	.0460
401	1615-1	Abbar	1	15/10/95	5.2	42	10.34	11.02	8.90	.0230	.0180	.0290	5.80	4.36	2.51	.0280
402	1632-1	Masal	3	15/10/95	5.2	52	10.27	11.94	10.36	.0210	.0096	.0210	4.36	4.90	3.43	.0290
403	1664-2	Khanzanun	1	23/10/95	4.9	8	1.48	2.58	1.23	.1000	.0650	.1500	.32	1.33	.27	.2000
404	1620-5	Doab	3	26/10/95	3.4	20	1.74	4.63	3.96	.0330	.0110	.0120	.27	2.67	.81	.0740
405	1590-3	Sisakht	1	02/11/95	3.6	15	3.24	3.73	3.42	.0450	.0340	.0370	2.46	2.48	2.41	.0450
406	1538	Kolur	1	03/11/95	3.6	16	4.65	8.27	2.17	.0320	.0200	.0720	.92	2.58	.37	.0640
407	1586	Ziaratali -N. Bandarabbas	1	06/11/95	5.1	21	7.99	8.65	9.78	.0350	.0190	.0250	3.52	4.72	3.70	.0460
408	1625-2	Ghaleh-Ganj (Kahnoudi)	1	06/11/95	5.1	49	6.59	8.14	6.51	.0460	.0320	.0530	1.72	3.24	1.66	.0790
409	1539	Mashad (Sakht-Azma)	4	09/11/95	5.6	70	8.65	10.86	9.78	.0490	.0370	.0400	3.30	4.99	5.05	.0700
410	1559	Khurmodj	1	14/11/95	4.2	15	4.21	6.48	3.83	.0560	.0260	.0500	2.17	3.32	1.36	.0690
411	1544	Silvaneh	4	14/11/95	4.4	16	3.50	5.16	4.07	.0880	.0430	.0630	.85	2.15	1.75	.1600
412	1560-1	Lali	3	24/11/95	4.5	19	2.79	3.69	4.51	.3100	.3000	.2400	.66	2.29	1.84	.5600
413	1572	Masjed-Soleyman	3	24/11/95	4.5	45	8.78	6.09	5.89	.0320	.0180	.0610	3.23	2.73	2.70	.0470
414	1560-2	Lali	3	24/11/95	4.0	20	3.44	4.71	3.63	.0430	.0330	.0320	.79	2.55	1.29	.0720
415	1560-3	Lali	3	25/11/95	3.8	18	2.84	3.71	3.63	.0430	.0330	.0320	.79	2.55	1.29	.0720
416	1560-4	Lali	3	27/11/95	5.0	18	6.72	4.23	4.84	.1400	.2000	.2200	1.47	2.84	1.35	.2700
417	1560-5	Lali	3	27/11/95	3.8	8	3.95	3.92	4.09	.0370	.0350	.0390	1.72	2.52	1.72	.0500
418	1590-4	Sisakht	1	14/12/95	3.5	14	2.74	2.64	2.80	.0450	.0630	.0490	1.57	1.76	.53	.0870
419	1549-3	Ammarloo	3	29/12/95	3.9	12	1.66	2.79	2.34	.0770	.0320	.0590	1.01	1.70	.53	.0870
420	1566	Shiraz	4	31/12/95	4.7	35	9.44	8.62	8.26	.0240	.0230	.0260	3.63	6.32	3.35	.0340
421	1602-1	Kavar Dam	2	31/12/95	4.7	33	8.79	9.89	8.53	.0460	.0180	.0390	3.62	5.36	4.26	.0640
422	1602-2	Kavar Dam	2	31/12/95	4.8	24	8.45	9.47	9.11	.1100	.0350	.0800	3.67	4.94	3.89	.1400
423	1602-3	Kavar Dam	2	31/12/95	4.0	32	5.59	10.97	6.95	.0350	.0078	.0280	2.43	6.33	2.40	.0460
424	1571-1	Shabankareh	4	23/01/96	4.1	16	4.32	5.62	7.18	.0700	.0530	.0400	.78	2.93	2.78	.1500
425	1571-2	Shabankareh	4	23/01/96	3.5	16	2.25	4.45	3.95	.0410	.0280	.0230	.45	2.83	1.26	.0810
426	1571-3	Shabankareh	4	23/01/96	3.7	16	8.97	4.18	3.90	.0130	.0420	.0420	3.20	2.90	1.08	.0190
427	1571-4	Shabankareh	4	24/01/96	4.5	18	2.76	5.71	3.83	.2100	.0830	.1400	.73	2.96	1.11	.3600
428	1571-5	Shabankareh	4	24/01/96	4.4	18	6.84	7.84	8.04	.0200	.0150	.0170	.94	3.54	2.19	.0480
429	1571-6	Shabankareh	4	24/01/96	4.7	16	7.48	10.72	8.65	.0250	.0180	.0240	.93	3.78	2.26	.0620
430	1583-3	Saadabad	1	24/01/96	4.4	21	13.22	17.01	14.99	.0750	.0280	.0550	10.39	12.00	11.13	.0740
431	1583-4	Saadabad	1	24/01/96	4.7	21	5.07	8.75	5.28	.0470	.0180	.0390	1.58	4.59	1.91	.0750
432	1571-10	Shabankareh	4	24/01/96	4.6	24	19.32	16.75	16.48	.0720	.0770	.1000	13.09	13.78	11.80	.0770
433	1571-12	Shabankareh	4	24/01/96	3.7	20	5.44	6.69	5.50	.0160	.0160	.0170	1.11	3.14	1.52	.0320
434	1571-13	Shabankareh	4	24/01/96	3.7	18	7.39	7.95	3.99	.0150	.0140	.0290	2.31	3.28	.69	.0240
435	1571-14	Shabankareh	4	24/01/96	3.7	16	7.93	7.55	4.62	.0160	.0140	.0270	2.34	3.07	.47	.0250
436	1571-15	Shabankareh	4	24/01/96	3.6	15	5.39	6.06	4.96	.0190	.0190	.0230	1.46	2.62	.84	.0320
437	1571-16	Shabankareh	4	24/01/96	3.5	17	7.05	5.38	4.14	.0110	.0190	.0210	2.48	2.73	.86	.0170
438	1571-17	Shabankareh	4	24/01/96	3.5	18	12.73	9.53	5.59	.0047	.0076	.0150	7.17			

Chapitre 6

L'Atténuation des Mouvements Forts en Iran

Résumé Les données des mouvements forts en Iran sont utilisées pour établir les lois d'atténuation empiriques pour différents paramètres de mouvements forts: A_{max} , V_{max} , D_{max} et les ordonnées spectrales des spectres de réponses. Les variables explicatives sont la magnitude, la distance hypocentrale et les conditions de site. Deux approches ont été essayées pour les régression (une et deux étapes), et les résultats sont très proches l'un de l'autre: les résultats de la première approche (deux étapes) sont présentés d'abord, ensuite viennent ceux de la deuxième approche (une étape). Les résultats de la régression faite en une seule étape sous-estiment les mouvements forts à faible distance ($< 20\text{km}$), mais les surestiment pour des distances supérieures à 100km par rapport aux résultats de la régression en deux étapes.

La base de données se compose de 468 accélérogrammes, en 3 composantes, enregistrés au cours des 24 dernières années en Iran. Basé sur ces données, on divise le pays en deux régions géographiques: pour la période d'observation (1975-1997), les plus forts séismes ont eu lieu dans les régions de l'Iran central et dans l'Alborz ($M > 7$), et ont été enregistrés jusqu'à 220km de distance, alors que les séismes du Zagros ont été plus modérés ($M4-6$), et enregistrés seulement jusqu'à environ 60 km. Cette différence, et une différence possible entre l'atténuation dans ces deux grandes régions, impose des coefficients différents pour les relations d'atténuation. Les effets de site observés à partir de ces régressions ne sont pas très importants, mais malgré tout sont en accord avec la classification de site préalablement choisie. Les effets non-linéaires ont aussi été recherchés dans ces études mais les résultats semblent montrer des phénomènes contraires avec les amplifications d'autant plus grandes que le mouvement est fort; aucune explication exacte n'a pu être trouvée pour cette observation, mais peut-être ces résultats sont la réponse de sites d'alluvions assez raides dans le champ-proche des séismes, quant les niveaux des nappes phréatiques sont très bas. Dans notre proposition pour la poursuite des installations de stations accélérométriques en Iran, nous insistons sur l'importance du problème du champ-proche en Iran. Les réseaux locaux dans les régions à sismicité très importante peuvent aussi fournir les données plus précises pour la suite des études sur la loi d'atténuation en Iran.

Strong Motion Attenuation in Iran

Mehdi Zaré, Pierre-Yves Bard and Mohsen Ghafory-Ashtiany

Article en préparation pour soumettre au "Bulletin of the Seismological Society of America"

Abstract The Iranian strong ground motions data are used to derive the empirical attenuation laws for different strong motion parameters: peak acceleration, peak velocity, peak

displacement, response spectral ordinates. The empirical relationships are established for the strong motion parameters as a function of moment magnitude, hypocentral distance, and a constant parameter representing the site conditions. The one and two step approaches for the regressions are applied, and the results are found to be near to each other, while only the results for the two step approach are presented in this paper. The data set consists of 468 three component accelerograms, all recorded during the last 24 years in Iran. It is split in two subsets corresponding to two geographical areas: during the period of observation (1975-1997), stronger earthquakes occurred in central Iran and Alborz region and were recorded at distances as far as 220km, whereas the Zagros belt experienced only moderate events ($M4-6$) recorded at distances up to about 60km. This difference, and a probable difference in attenuation between these two main regions, cause different coefficients for the attenuation relationships. The soil effects are considered in the regressions: the resulting site dependence is not very large, but does agree with our previous site classification for Iran.

6.1 Introduction

The Iranian strong motion records are obtained by a national network operated by BHRC (Building and Housing Research Center) and installed in different cities and villages throughout the country (Figure 6.1). As it is outlined in a previous paper (Bard et al 1998), this network first consisted of Kinemetrics SMA-1 analog instruments (1975-1989), which were complemented by numerous SSA-2 digital instruments after the Manjil earthquake of 1990. By the end of 1997, the number of instruments was reported to be 1000 stations, while the location of 386 SSA-2 and 79 SMA-1 stations are reported and plotted in Figure- 1. The stations are mainly installed within cities or villages for easy maintenance. A preliminary listing of the recorded data as of 1993 was published by BHRC. A complete catalog is available in Bard et al 1998).

The attenuation relationships in Iran have never been established using the whole Iranian data set. The purpose of this paper was therefore to fill that gap. The mentioned cleaned catalog is used, that keeps only the data for which the magnitude and epicentral distance are known, and for which the signal to noise ratio is satisfactory. The data set consists of 468 three component records. The source parameters were derived from the teleseismic studies for 279 records (Bard et al 1998) and directly from the strong motion records for the remaining 189 records, using a source model (Zaré et al 1999b). The site conditions were devoted special attention and measurements, which led to a new categorization in four different site classes, on the basis of H/V ratio for strong motion records. Details may be found in Zaré et al 1999a.

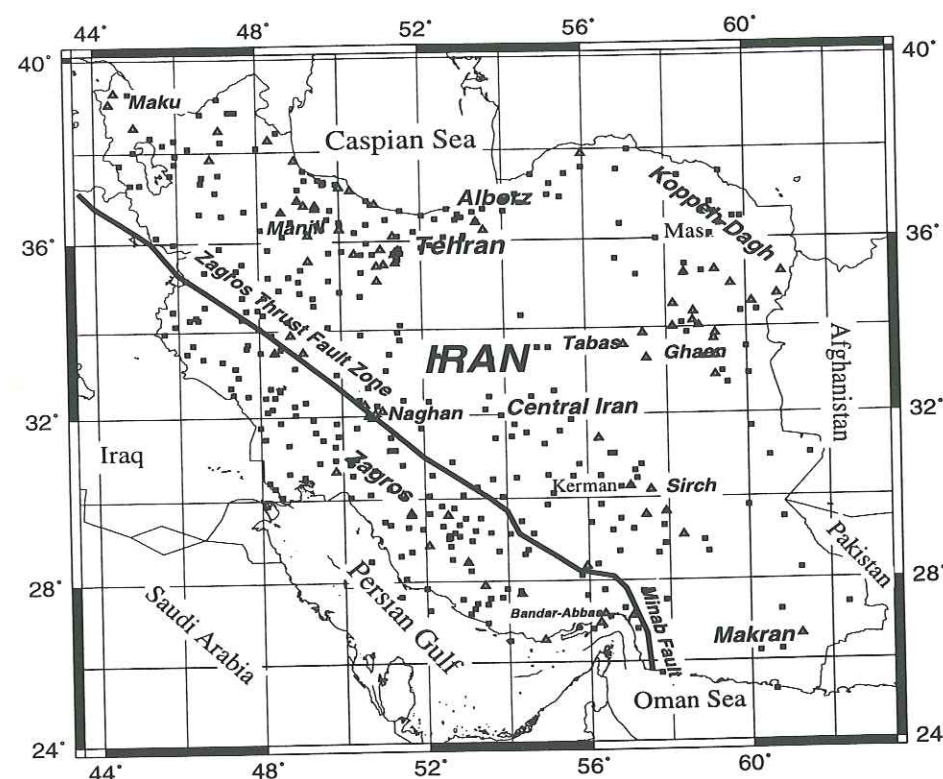


FIG. 6.1 – The strong motion network of Iran (stations installed by the end of 1996) the location of the new instruments are not still reported. The SSA-2 instruments are shown with triangles and the SMA-1 station are marked with quadrangles (special thanks to H. Mirzaei-Alavijeh of BHRC for the location of the new SSA-2 instruments). Iranian seismogenic zones and the Zagros thrust fault zone-Minab fault, which represent the frontier between the Alborz-Central Iran area and the Zagros area, are shown on the map.

The scope of this study is to investigate attenuation laws for the strong motions in Iran, in form of different parameters. An attempt was also performed to look for some difference in the attenuation in different regions. Another scope was to provide the design spectra for sample sites in Alborz (Tehran, on a rock site) and in Zagros (a sample site on the Persian Gulf).

In this article the methodology of the study is explained first, followed by the criteria to establish the data-base. The results of the study are then presented for the various parameters. The coefficients of the regression are presented not only for the spectral values but also for the parameters such as peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD). All coefficients are presented for horizontal and vertical components and separated for the Zagros and non-Zagros region (Alborz-Central Iran), and finally for the entire of the Iranian data.

6.2 Methodology

The establishment of the attenuation relationships for a given region may provide information to be used in other regions with similar characteristics. Meanwhile, it has been repeatedly claimed in recent years that a attenuation relationship, as an empirical model fitted to the data from a specific area, may not be easily used in other regions with different tectonic and crustal specifications (Abrahamson and Silva 1997, Abrahamson and Shedlock 1997).

6.2.1 The applied approaches

To establish the attenuation relationships for Iran, the approach presented by Joyner and Boore (1981) and Fukushima and Tanaka (1990) was followed. A two-step regression is used to fit a model to multiple independent variables (magnitude, distance, site,...). In this method the parameters controlling distance and site effects dependence and a set of amplitude factors, one for each event, must be determined in the first step, by maximizing the likelihood of the set of observation. The determination of the parameters controlling the magnitude dependence is then performed in a second step, by maximizing the likelihood of the set of amplitude factors (Joyner and Boore 1993).

Another possible approach is the one-step method, in which all the parameters are obtained simultaneously by maximizing the likelihood of the set of observations. This approach, which is used by Joyner and Boore (1993) and Brillinger and Preisler (1984, 1985), yields similar results to the two-step method for the spectral ordinates using the north-western American data (Boore et al 1994).

6.2.2 Fundamental form

The genuine form of the dependence is:

$$\log A = a \cdot M_w + b \cdot X - d \cdot \log X + c_i \cdot S_i + \sigma \cdot P \quad (6.1)$$

where A is the strong motion parameter, a is the coefficient for magnitude M ; b is the coefficient related to the anelastic attenuation with distance X ; c_i is a constant depending on the sites class S ; σ_i is the sigma value of 84 percent ($P = 1$), to be added to the mean (50 percent values; $P = 0$). The d coefficient for the $\log X$ term is introduced to allow a geometrical

expansion which may be different from the body wave dependence. In this study the moment magnitude M_w is used for M and hypocentral distance is used for X (except for two cases which will be explained later). The site conditions are divided in 4 categories according to Zaré et al 1999a. In many of the computations presented below, d is set equal to 1, so that this regression formula is similar to:

$$y = \frac{k}{X} \cdot e^{-qX}$$

where k is a function of M , and q is a constant. This form represents a simple point-source geometric expansion with constant (Q) anelastic attenuation. We have examined the X^{-d} form, as shown in equation 6.1, such that:

$$y = \frac{k}{X^d} \cdot e^{-qX} \quad (6.2)$$

Joyner and Boore (1981) have shown that such form should apply only to a harmonic component of the ground motion, and not to the peak values, however its application to the peak values (determining empirically) would be a proper approximation.

Ambraseys (1995) proposed attenuation relationships for Europe using the same model. He eliminated the anelastic attenuation coefficient term $b \cdot X$, for the vertical component estimations claiming that for the vertical records (of European data) of magnitudes M_s 4.0-7.9 and the focal depths less than 30km, a two-step regression was found to be inadequate in size to determine both the anelastic and geometric distance terms (Ambraseys 1995, Ambraseys and Simpson 1996). The distance term used by Ambraseys in the mentioned papers and by Joyner and Boore (1981), Boore et al (1997) is:

$$X = (R^2 + h^2)^{0.5}$$

where R is the distance to the surface projection of ruptured area, and h is the focal depth. Fukushima and Tanaka (1990) and Fukushima et al (1988) have defined the term of

$$X = (R + j \cdot 10^{e \cdot M})$$

where R is the rupture distance, j and e are the coefficients to be filtered, and M is the surface wave magnitude. This expression should reduce to $X = R$ for large distances. Hardly

and Helmberger (1980) have shown that near the faults, little geometrical attenuation exists. Therefore they suggested a functional form of the effective attenuation versus distance, for the strike-slip earthquakes. For this function, we have:

$$X = [R + C(M)]^{-t}$$

in which X is the modified epicentral distance for the near source earthquakes, R is the epicentral distance, $C(M)$ is a function of magnitude and t is a coefficient. This function is used by Campbell (1981) to present the attenuation relationship for the near-field strong motions:

$$PGA = a \cdot \exp b \cdot M [R + C(M)]^{-j}$$

The near-field attenuation is a function of the fault dimensions, therefore Esteva (1970) has shown that the parameter relating the fault rupture dimensions scales exponentially with magnitude; $C(M) = c_1 \exp(c_2 \cdot M)$.

6.2.3 Ground Motion Parameters

The regressions were performed for various ground motion parameters; PGA , PGV and PGD , and for the spectral accelerations ($S_a(T)$). The regression on $S_a(T)$ was fulfilled for 146 different frequencies and 5 percent of damping (between 0.1 and 50 Hz, periods between 0.02 and 10 seconds; see Annexe 9.1) such that more point are applied for low frequencies in comparison with the high frequencies. The general form of the attenuation relationship for the spectral acceleration (S_a) is;

$$\log S_a(T) = a(T) \cdot M_w + b(T) \cdot X - d \cdot \log X + c_i(T) \cdot S_i + \sigma(T) \cdot P \quad (6.3)$$

This relationship has the same form as equation 6.1, just the spectral acceleration and the coefficients a , b , c and σ are functions of the period (T). Caillot (1992) used a slightly different form of such formula with the Neperian logarithm of $S_a(T)$ and eliminating the term related to the anelastic attenuation coefficient, while adding a coefficient to observe the geometric expansion for the Italian data:

$$\ln S_a(T) = a(T) \cdot M_w + b(T) \cdot \ln X + c_i(T) \cdot S_i + \sigma(T) \cdot P$$

6.3 The input data-base

The data-base used as the input for this study consists of 468 three components accelerograms (169 analogs by SMA-1 instruments and 299 digitals by SSA-2 recorders, Appendix 6.1), recorded between 1975 and February 1996 by the national network (Figure 6.1). This data-base comprises 279 analog and digital records with fairly well known source parameters (Bard et al 1998) and 189 other digital accelerograms which were very well recorded, and for which no source data was directly available. The moment magnitude and hypocentral distance for these records have thus been estimated directly from the strong motion records. The hypocentral distance was obtained from the S-P time difference, while the seismic moment was directly calculated from the level of acceleration spectra plateau and the corner frequency (Zaré et al 1999b).

The magnitude range for the whole data set is $2.7 = M \leq 7.4$ while the range for hypocentral distances is $4 \leq X \leq 240 \text{ km}$ (Figure 6.2). The focal depths range is 9-133 km but the focal depth determination is very imprecise and the majority of the events are shallow (Bard et al 1998a). The two horizontal components of each record are included separately in the study, therefore the number of the horizontal records entered to the regressions was twice the vertical ones.

6.3.1 The magnitude values

The magnitude used here is the moment magnitude, to give a uniform and reliable scale. The moment magnitude was systematically calculated for the well recorded earthquakes (with little noise). When it was not possible to calculate M_w precisely because of the high noise level, other magnitudes were converted to M_w using the correlation with M_w specifically derived for Iran (Zaré et al 1999b). According to this correlation, M_w is taken equal to M_s for magnitudes greater than 6 and equal to mb and ML for magnitudes less than 6. Ambraseys and Free (1997) showed for a European data-base (including a few Iranian data) that such correlation exists between M_s and M_w not only for the moment magnitude relationship (Hanks and Kanamori 1979, used in Zaré et al 1998b) but also for a new empirical non-linear relationship established by them.

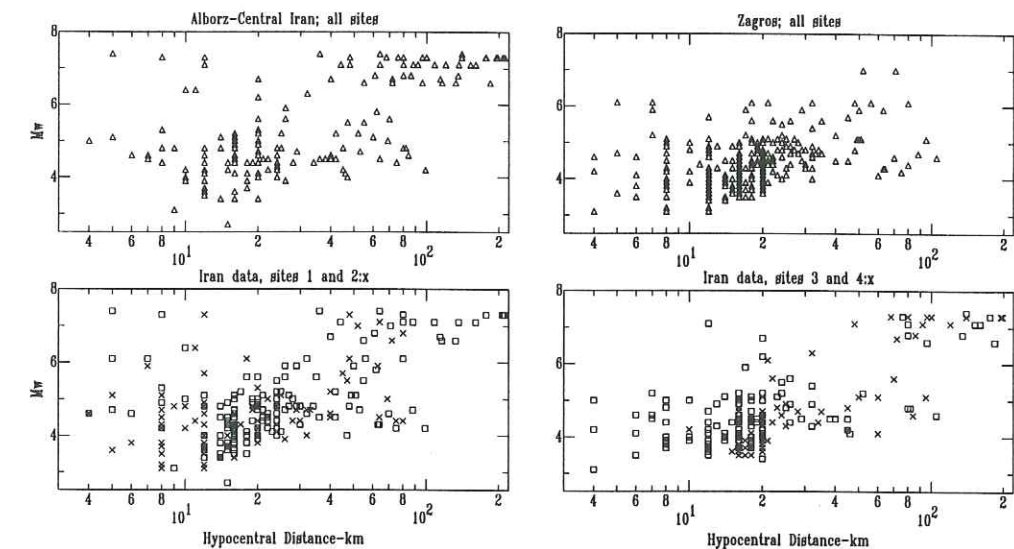


FIG. 6.2 – The statistics of the Iranian data for Alborz-Central Iran, Zagros and entire of the data; the attribution of the records to the site classes is shown for the entire of the data.

6.3.2 Distance parameter

When discussing the choice of the "distance parameter" one must keep in mind the significant uncertainties in teleseismic epicenter localizations and large uncertainties in determining focal depths for the Iranian earthquakes. It is important however to define this parameter so that the future use of the attenuation law will be easy.

The focal depths for most of the Iranian records (below $M_w 6.0$) are estimated using the teleseismic reports, because of the lack of a dense seismic array in Iran. This situation is similar even for some larger events ($M_w > 6.0$). Kadinsky-Cade and Barazanji (1982) showed that for the Zagros data in southern Iran, there is a discrepancy between the depths reported by ISC and those of NEIC. Neglecting the values of 33 km (depth at which events are arbitrarily located when the iteration process used in their location yields large residuals), the ISC depths are systematically reported to be greater than the NEIC depths.

The only earthquakes with M_w greater than 6.0 for which the focal depths are constrained by waveform observations are:

- The Sarkhun earthquake, 7 March 1975 ($M_s 6.1$ depth=11 km);
- The Khurgu, earthquake, 21 March 1977 ($M_s 7.0$, depth=12 km) (both by Jackson and

Mckenzie 1984);

- The Naghan, earthquake, 6 April 1977 ($M_s 6.1$, depth=43km), (Ni and Barazanji 1986);
- The Tabas, earthquake, 16 September 1978 ($M_w 7.4$, depth=10km, Berberian 1982);
- The Manjil, earthquake, 20 June 1990 ($M_w 7.3$, depth=19km, Eslami and Mozaffari 1992, and 14km, Berberian et al 1992);

We have decided to define the distance variable for the regression as the "hypocentral distance". This distance is controlled by the difference in the arrivals of the compressional and shear wave for each record. Such information is available without any ambiguity only with the SSA-2 digital records, since the SMA-1 instruments do not include any pre-event memory.

In the cases of near-source records (such as the Tabas record obtained at 5km distance from the Tabas 1978 earthquake fault, and Abbar record in the Manjil 1990 earthquake at 8km distance to fault zone), it was impossible to distinguish the phases and the first arrivals, so we have taken the distance to the fault zone (R_f) as our variable X (which has more physical concept than hypocentral distance; R_h). Ambraseys and Sbrulov (1998) indicated that in the near-field cases (such as Tabas record) the point-source model may over-estimate the predictions of peak values and spectral ordinates. They showed that the over-parameterization of the attenuation model may not reduce variability of the predictions from point-source models, however they suggested a better understanding of source location, direction and thickness of the non-seismogenic zone for the near-field records.

On the other hand, the Tabas record exhibits a very specific near-source spectra, such that it was estimated that an important directivity effect was probable on this record (Zaré 1996). It is hence suggested that for magnitudes greater than $M_w 7.0$, and distances less than 20km, and magnitudes greater than $M_w 6.0$ with distances less than 10km as well, the prediction of strong motion parameter should deserve a special study, for instance through a search of corresponding near-source records in the Iranian data-set or in another data-set which represents similar seismotectonic characteristics. In such conditions near-field records might be studied by a deterministic approach to predict the probable strong motion parameters.

Since the differences between the hypocentral and epicentral distances are not too large for shallow earthquakes (less than 35km depth), it is suggested that in further use of the presented attenuation laws in this article, the "surface distance to fault" be replaced in the formula whenever the estimation of the depth of the seismic source is impossible. We propose that such surface projected distance might give a good estimation of the hypocentral distances.

6.3.3 Geological areas

The Iranian data falls into two geological groups; the Zagros data and Central Iran and Alborz data (Figure 6.1). The Zagros thrust fault zone (Figure 6.1) is the main geologic frontier between the Zagros and non-Zagros regions. The pre-existing seismic data from Zagros area shows higher seismic activity rate than the other regions. In the Zagros area middle range magnitudes ($M 4-6$) are more frequent. In Alborz-Central Iran zone earthquakes are less frequent but have generally higher magnitudes than Zagros, and are therefore more destructive (Tabas earthquake, 1978, Central-Iran; and Manjil earthquake, 1990, Alborz). The Zagros thrust fault zone is the main geologic frontier between these two areas. On the other hand, the Zagros data are mostly recorded in the near-field distances (below 60km), while there exist records at distances greater than 220km in Alborz-Central Iran region. The time of the event, the distance to source and the exact timing on the digital records (if accessible), the magnitude of the corresponding event and the amplitude of the records were the main criteria to attribute each record to the seismic events in these zones. Since the strong motions are limited to relatively near distances, and most of our records were obtained within 50km (Figure 6.2), the events are distinguishable for each of the mentioned zones.

6.3.4 Site Categorization

Site conditions are considered through the categorization in four site classes on the basis of the receiver function (Zaré et al 1999a). Site class 1 is defined as sites that do not exhibit any significant amplification below 15 Hz. It corresponds to rock and stiff sediment sites with an average S-wave velocity over the top 30 meters in excess of 700m/sec. Site class 2 consists of sites for which the receiver function (RF) exhibits a fundamental peak exceeding 3 at a frequency located between 5 and 15 Hz. It was shown to correspond to stiff sediments and/or soft rocks with V_{s30} between 500 and 700 m/sec. Site class 3 consists of the sites for which RF shows a peak with an amplitude exceeding 3 between 2 and 5Hz, and corresponds to alluvial sites with V_{s30} between 300 and 500 m/sec. Finally site class 4 is defined as sites for which RF indicates peaks with amplitudes greater than 3 at frequencies below 2Hz, and it may be viewed as corresponding to thick soft alluvium. This ranking was the result of geotechnical measurements on 50 sites (compressional and shear wave velocity, microtremors) and the calculation of the receiver function for strong motions using three component accelerograms. This categorization shows some similarity to that of Boore et al (1993, 1994) (based on the average V_s for the top 30m) for the northwestern American data. The average V_s limits to distinguish the site classes

in Boore et al (1993,1994) reports are 180 m/sec, 360 m/sec, 750 m/sec and greater than 750 m/sec (to be compared with our values of 300, 500 and 700 m/sec).

6.3.5 Fault mechanism

According to the regional tectonic conditions of Iranian plateau, the fault mechanisms of most of the earthquakes are compressional, strike-slip or a combination of these two mechanisms. In an earlier study (Bard et 1998), it was shown that out of the 100 focal mechanisms of the records that are available, 40 correspond to strike-slip/reverse mechanisms, 31 to pure strike slip, 24 to pure reverse and 4 to pure vertical plane. Hence further usage of the attenuation law in this article should be limited to the sources with such mechanisms. It must be noted that since the time of installation of the Iranian accelerometric network, no earthquake with a normal (extension) fault solution has been recorded in this network.

6.4 Results

The results of regressions are presented in the form of spectral ordinates and the peak values. The values of the coefficients and the residuals between the predicted and the observed values for the maximum of the strong motion parameters (PGA, PGV and PGD) are estimated. The predicted spectra are presented for two different situations in Zagros and Alborz-Central Iran, and the smoothed (design) spectra to be proposed. The representative spectra are calculated using the attenuation laws for the spectral accelerations (S_a).

As explained before for the equations 6.1, 6.2, and 6.3, surface wave-like attenuation may be reproduced applying $d = 0.5$ for $d \cdot \log X$. To find the lowest possible standard deviation, different values are examined for d , and the lowest sigma value were obtained for $d = 0.3$ on the vertical components and $d = 0.1$ for the horizontal components. These variations may be investigated further to find the other effective factors in the attenuation in the Iranian crust. However we will present here only the calculations with $d = 0.5$ and $d = 1$, because of their physical meaning in relation with surface and body waves, respectively.

The calculations on the response spectra are limited to the frequency bands for which a good signal to noise ratio (R_{sn}) could be found. The accelerometric data are already band-pass filtered, considering a R_{sn} fixed to be 3 (Bard et al 1998, Zaré et al 1998b). Therefore in the frequency bands for which R_{sn} was lower than 3, the accelerogram is considered to be noisy and the spectral values are eliminated from the calculations. The sum of the selected point for

the regressions after such sieving is shown in Figure 6.3. According to this figure, the records in Alborz-Central Iran which were mostly analog (SMA-1) records contained a lot of noise and suffered more from the filters, while the Zagros data which are mostly digital show proper signals.

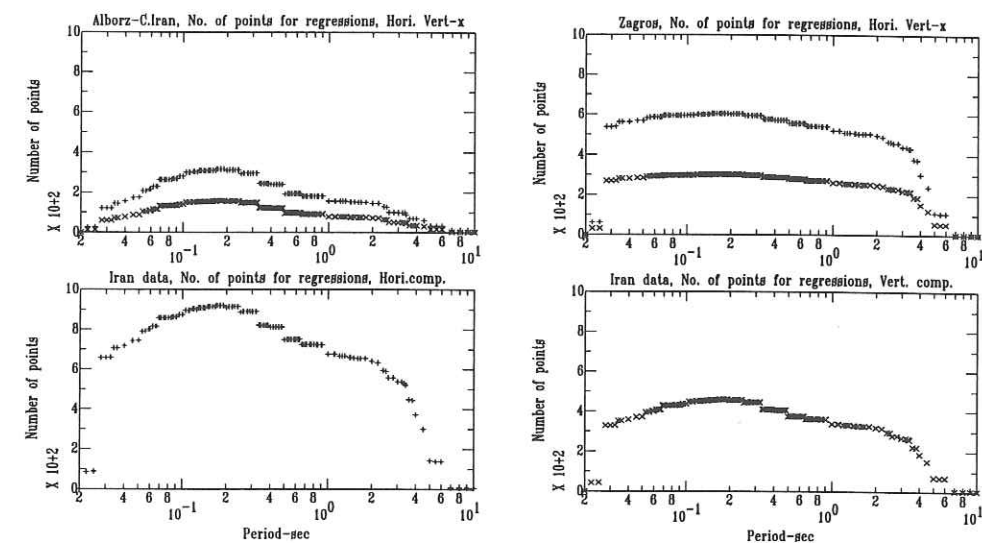


FIG. 6.3 - Number of spectral values after eliminating the values with low signal to noise ratios.

6.4.1 Attenuation coefficients for peak values

The strong motion parameters (A value in equation 6.1) selected in this section are PGA, PGV and PGD. Other parameters (energy and duration) were investigated in a separate study (Zaré et al 1999b).

The values of the coefficients of the regression for PGA, PGV and PGD in equation 6.1 are shown in Tables-6.1 to 6.3. The attenuation curves (Figures 6.4, 6.5 and 6.6) are presented for Alborz-Central Iran, Zagros and the Iranian data (entire of the data-base). The Iranian strong motion data show some differences in at least two main regions: Zagros and Alborz-Central Iran (Tables-6.1 to 6.3).

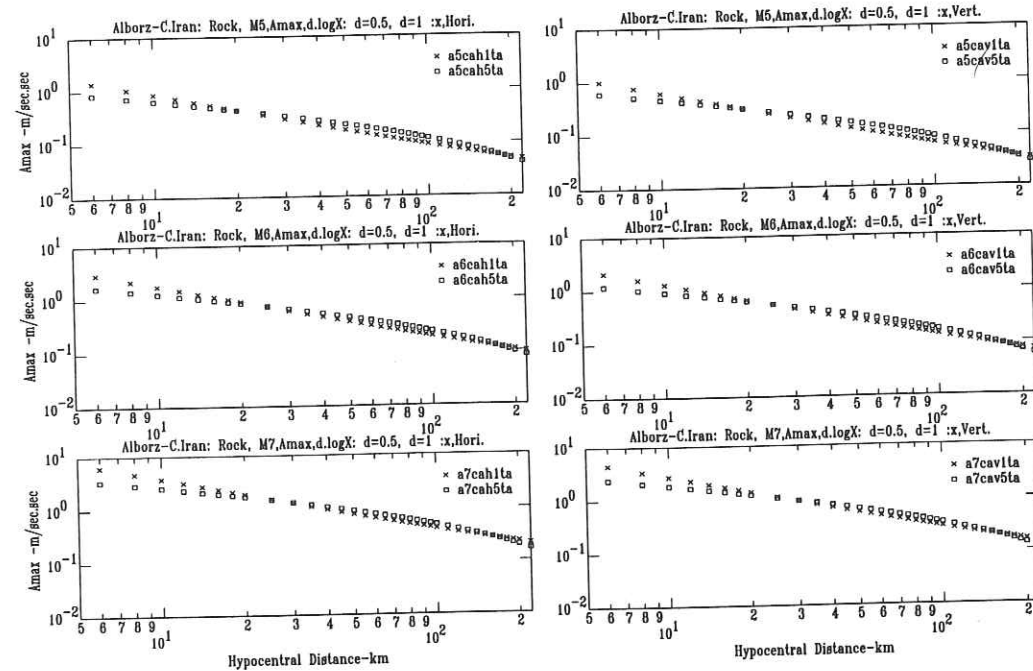


FIG. 6.4 – Attenuation of PGA with distances for magnitudes 5.0, 6.0 and 7.0, in Alborz-Central Iran, left: horizontal and right: vertical components; quadrangle: $d=0.5$, cross: $d=1$.

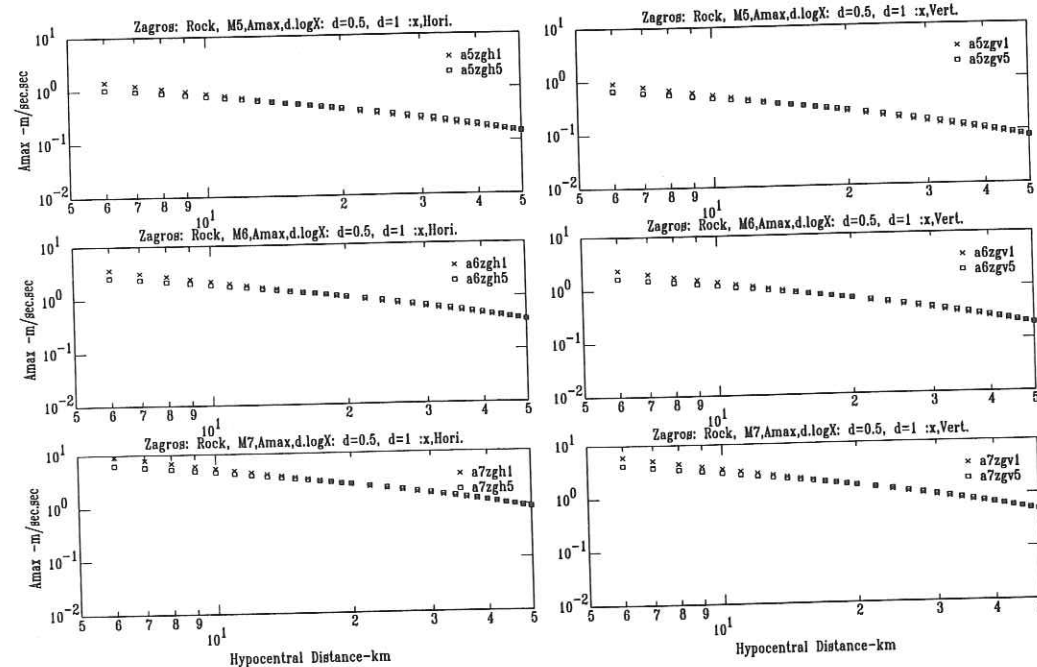


FIG. 6.5 – The attenuation of PGA with the distances for the magnitudes 5.0, 6.0 and 7.0, for Zagros.

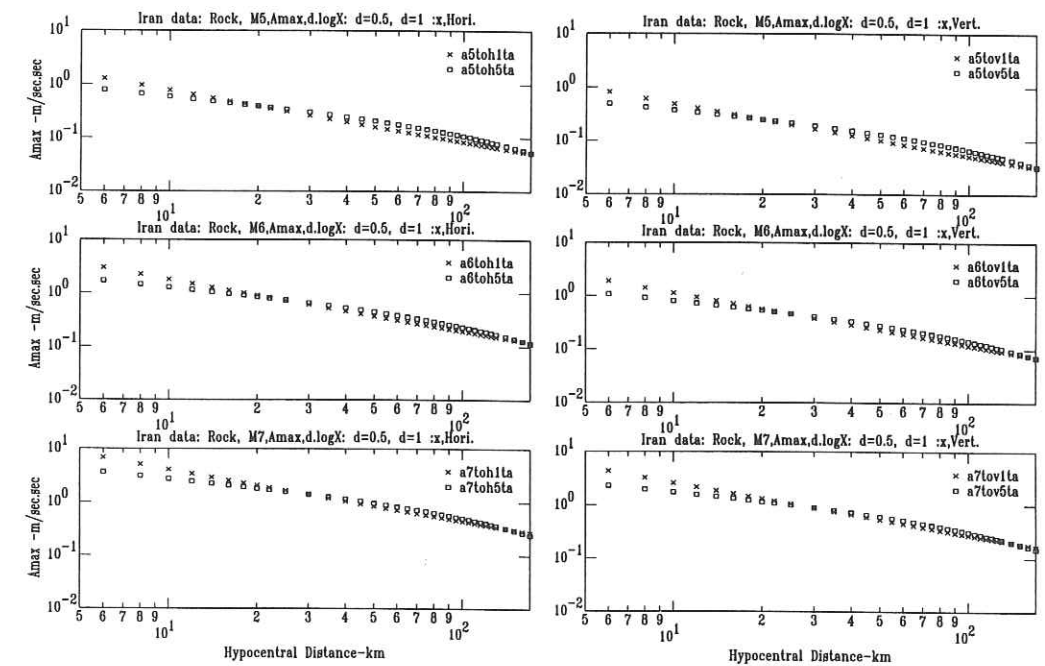


FIG. 6.6 – The attenuation of PGA with the distances for the magnitudes 5.0, 6.0 and 7.0, for the entire of the data-base.

The regressions were performed for $d = 0.5$ and $d = 1$, but the coefficients are just presented for $d = 1$, because the differences between the sigma values in these two case were not significant. The most important differences between these two cases is observed for the PGA values in Alborz-Central Iran data at distances less than 20km (Figure 6.4), where the regressions with $d = 1$ give the higher values for PGA.

Table 6.1: The coefficient for the attenuation of PGA, applying equation 6.1

Region/comp.	a	b	c1	c2	c3	c4	Sigma
Central Iran, Alborz (Vert.)	0.322	-0.0003	-0.828	-0.754	-0.971	-0.788	0.352
Central Iran, Alborz (Hori.)	0.322	-0.0004	-0.688	-0.458	-0.720	-0.585	0.394
Zagros (Vertical comp.)	0.406	-0.0038	-1.262	-1.333	-1.230	-1.777	0.356
Zagros (Horizontal comp.)	0.399	-0.0019	-1.047	-1.065	-1.020	-0.975	0.329
Iranian data (Vertical)	0.362	-0.0002	-1.124	-1.150	-1.139	-1.064	0.336
Iranian data (Horizontal)	0.360	-0.0003	-0.916	-0.852	-0.900	-0.859	0.333

Table 6.2: The coefficient for the attenuation of PGV, applying equation 6.1, for 381 cases

Region/comp.	a	b	c1	c2	c3	c4	Sigma
Central Iran, Alborz (Vert.)	0.466	0.0014	-3.108	-3.178	-3.328	-3.069	0.363
Central Iran, Alborz (Hori.)	0.471	0.0006	-2.865	-2.896	-2.969	-2.737	0.360
Zagros (Vertical comp.)	0.612	0.0028	-4.011	-4.101	-3.984	-3.917	0.319
Zagros (Horizontal comp.)	0.588	0.0040	-3.627	-3.651	-3.632	-3.502	0.315
Iranian data (Vertical)	0.548	0.0018	-3.675	-3.761	-3.702	-3.610	0.336
Iranian data (Horizontal)	0.538	0.0014	-3.335	-3.360	-3.348	-3.224	0.338

Table 6.3: The coefficient for the attenuation of PGD, applying equation 6.1, for 346 cases

Region/comp.	a	b	c1	c2	c3	c4	Sigma
Central Iran, Alborz (Vert.)	0.828	-0.0029	-5.861	-6.127	-6.023	-5.753	0.521
Central Iran, Alborz (Hori.)	0.828	-0.0036	-5.694	-5.837	-5.771	-5.352	0.489
Zagros (Vertical comp.)	0.784	0.0084	-6.043	-6.164	-6.144	-6.109	0.312
Zagros (Horizontal comp.)	0.797	0.0086	-5.893	-5.973	-5.954	-5.743	0.334
Iranian data (Vertical)	0.830	-0.0003	-6.051	-6.213	-6.163	-6.081	0.337
Iranian data (Horizontal)	0.829	-0.0010	-6.831	-5.942	-5.899	-5.645	0.388

The 'b' value, which represents the anelastic attenuation, was found to be the positive in some cases in Tables 6.1 to 6.3. Such abnormal values is to be connected to the fixed values of 1 or 0.5 in the logX term in our regressions. The 'b' values, however, are very low. The residuals between the recorded and observed values of each of the parameters are shown in Figures 6.7 to 6.12, against the hypocentral distance and M_w . These residuals are presented for $d = 0.5$ and $d = 1$ (in equation 6.1), and it is evident that the difference of the residuals for $d = 0.5$ and $d = 1$ is not significant. In some cases (Figures 6.7, 6.9 and 6.11) lower residuals might be seen at greater distances for values calculated with a $d = 0.5$, especially for Alborz-Central Iran data. However these differences are not very large. The difference of the sigma values are found to be very low (for $d=0.5$ and $d=1$), while the sigma values are lower for $d=0.5$ (for Iranian data, sigma values for the horizontal components, for logarithm of PGA is found to be 0.333 and 0.318 while for logarithm of PGV they are 0.338 and 0.317 and for logarithm of PGD, they are 0.388 and 0.362 for $d=1$ and $d=0.5$, respectively).

Univ. J. Fourier - O.S.U.G.
 MAISON DES GEOSCIENCES
 DOCUMENTATION
 B.P. 53
 F. 38041 GRENOBLE CEDEX
 Tél. 04 76 63 54 27 - Fax 04 76 51 40 58
 Mail: plalour@ujf-grenoble.fr

20 AOÛT 2003

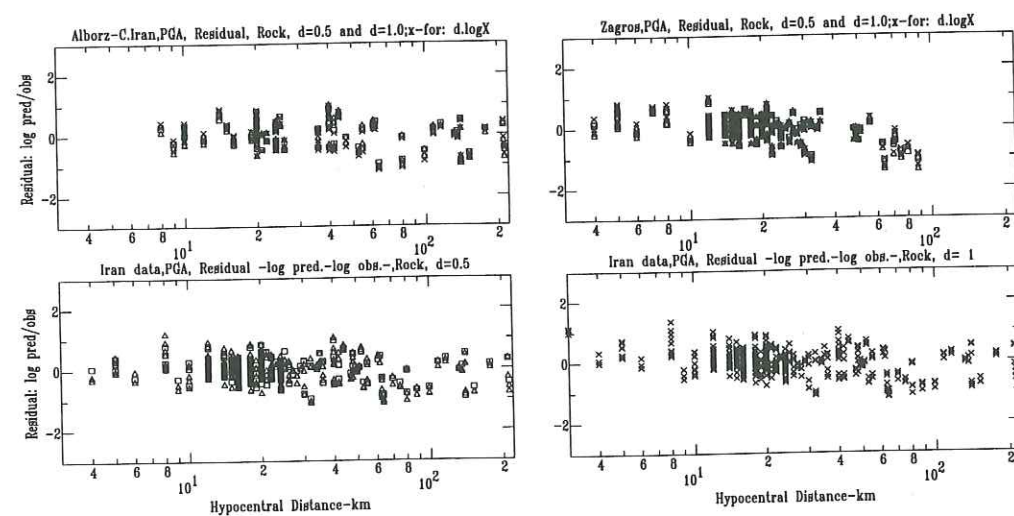


FIG. 6.7 – The residual (\log predicted – \log observed) of the PGA against distance, on rock sites, for Alborz-Central Iran, Zagros and entire of the data-base; the results are shown for $d = 0.5$ (quadrangles) and $d = 1$ (crosses) for Alborz-Central and Zagros; the $d=0.5$ and $d=1.0$ results are separated for Iran data (below).

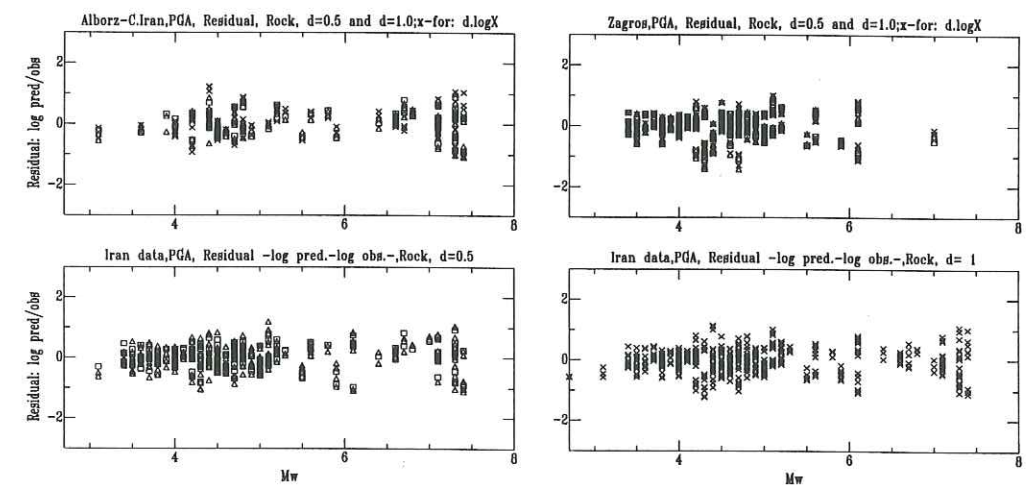


FIG. 6.8 – The residual (\log predicted – \log observed) of the PGA against M_w , on rock sites, for Alborz-Central Iran, Zagros and entire of the data-base; the results are shown for $d = 0.5$ (quadrangles) and $d = 1$ (crosses) for Alborz-Central and Zagros; the $d=0.5$ and $d=1.0$ results are separated for Iran data (below).

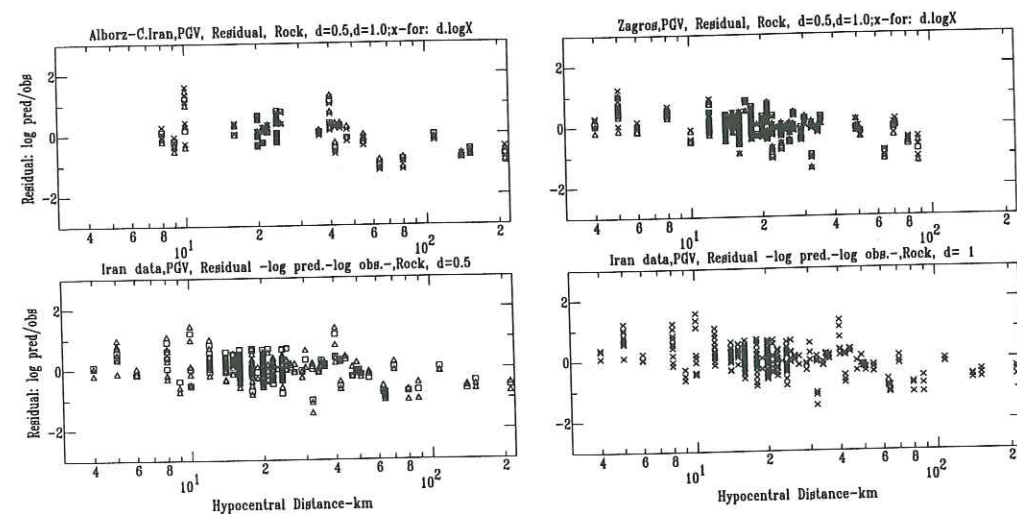


FIG. 6.9 – The residual (log predicted – log observed) of the PGV against distance , on rock sites, for Alborz-Central Iran, Zagros and entire of the data-base; the results are shown for $d = 0.5$ (quadrangles) and $d = 1$ (crosses) for Alborz-Central and Zagros; the $d=0.5$ and $d=1.0$ results are seperated for Iran data (below).

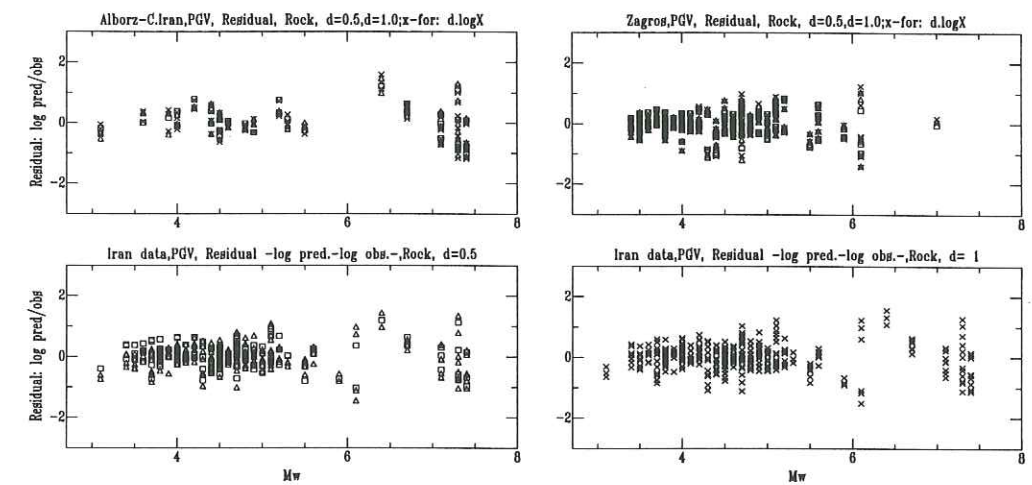


FIG. 6.10 – The residual (log predicted – log observed) of the PGV against M_w , on rock sites, for Alborz-Central Iran, Zagros and entire of the data-base; the results are shown for $d = 0.5$ (quadrangles) and $d = 1$ (crosses) for Alborz-Central and Zagros; the $d=0.5$ and $d=1.0$ results are seperated for Iran data (below).

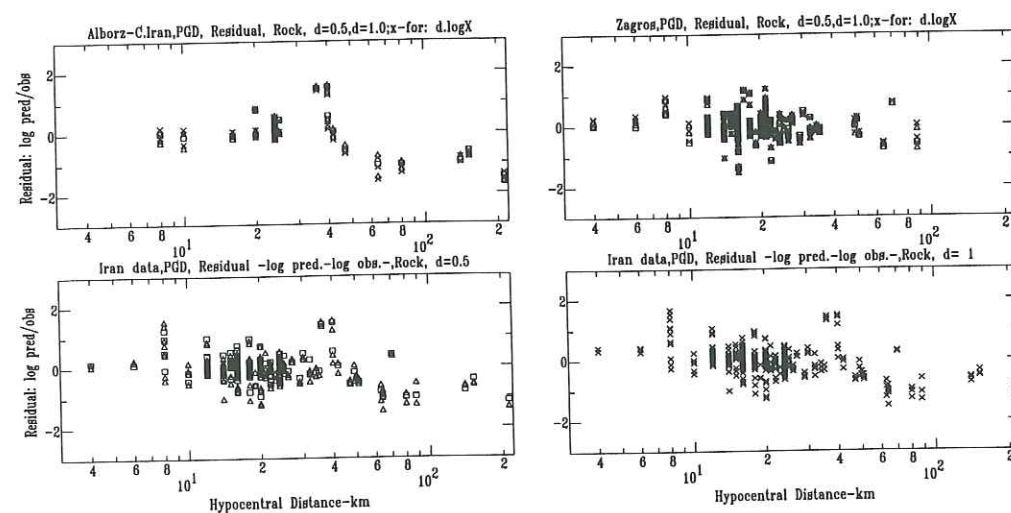


FIG. 6.11 - The residual (log predicted - log observed) of the PGD against distance, on rock sites, for Alborz-Central Iran, Zagros and entire of the data-base; the results are shown for $d = 0.5$ (quadrangles) and $d = 1$ (crosses) for Alborz-Central and Zagros; the $d=0.5$ and $d=1.0$ results are separated for Iran data (below).

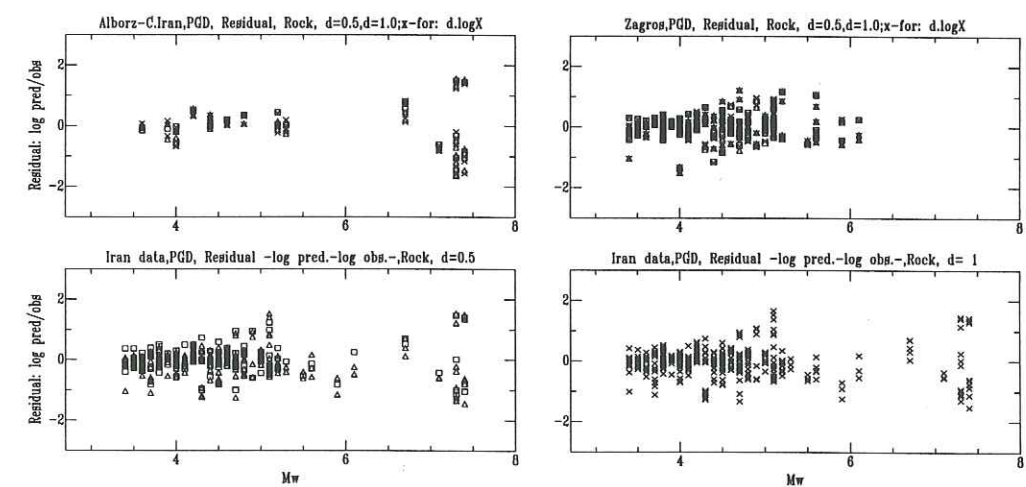


FIG. 6.12 - The residual (log predicted - log observed) of the PGD against M_w , on rock sites, for Alborz-Central Iran, Zagros and entire of the data-base; the results are shown for $d = 0.5$ (quadrangles) and $d = 1$ (crosses) for Alborz-Central and Zagros; the $d=0.5$ and $d=1.0$ results are separated for Iran data (below).

6.4.2 Attenuation coefficients for spectral ordinates

The acceleration response spectra are calculated for all the records, keeping just the frequency bands with a R_{sn} ratio greater than 3. According to Figure 6.3, the analog records (most of the Alborz-Central Iran data) are much noisy at long periods, leading to a low number of useful data (Figure 6.13). The coefficients of a , b and $c1$, as well as the amplification of the second, third and fourth site classes ($c2 - c1$, $c3 - c1$ and $c4 - c1$) are presented separately for Alborz-Central Iran, Zagros and whole Iran, for different periods between 0.05 to 4 seconds (Figures 6.13 to 6.16).

The values for $d = 0.5$ are shown only for entire of the Iranian data (Figure 6.16). The values of sigma are generally lower for $d = 0.5$ in all periods, but still for the spectral values, such difference is not large. Finally, according to the difference between the results with $d = 1$ and $d = 0.5$ in the near-field and the fact that using $d = 0.5$ will underestimate parameters in near-field area (Figure 6.4 to 6.6), it is proposed to take $d = 1$ in this paper, which may be a more conservative approach. Additional strong records in near-field conditions in Iran are needed for more detailed investigations.

According to Figure 6.3, the reliable period bands for the different regions are 0.05 to 1 seconds for Alborz-Central Iran and 0.03 to 3 sec for the Zagros data. Therefore the great instability for the Alborz-Central Iran results after 0.5sec (Figure 6.13) might be understood.

The a values increase when the period increases (Figures 6.13 to 6.16), which means an increasing magnitude dependence with longer periods as expected.

The positive b values for very large periods (beyond 3sec) might correspond to insufficient data (Figures 6.13 to 6.16). On the other hand, the negative b values at short periods may be an indication that attenuation of body waves were dominant, which in consequence gives more realistic values (negative sign for the coefficient of anelastic attenuation). The frequency content of the Zagros data is meaningful for such behavior; the Zagros records are representative for higher frequency, for which the body waves are more dominants. The same discussion might be done for the Iranian data (Figures 6.15 and 6.16) while the tendency for the positive 'b' values is evident when the period increases.

The site coefficients are consistent with the detailed site study on the Iranian strong motion sites (Zaré et al, 1999a). Amplifications at short periods ($< 0.2\text{sec}$) for the site class 2, in middle range periods (0.2 to 0.5 seconds) for site class 3, and and large periods ($> 0.5\text{sec}$) for site class 4, for most of the cases, do agree with the previous defined limits. However, the discrepancies from these limits seem to be significant for $c3$ and $c4$ for Alborz-Central Iran data

(Figure 6.13).

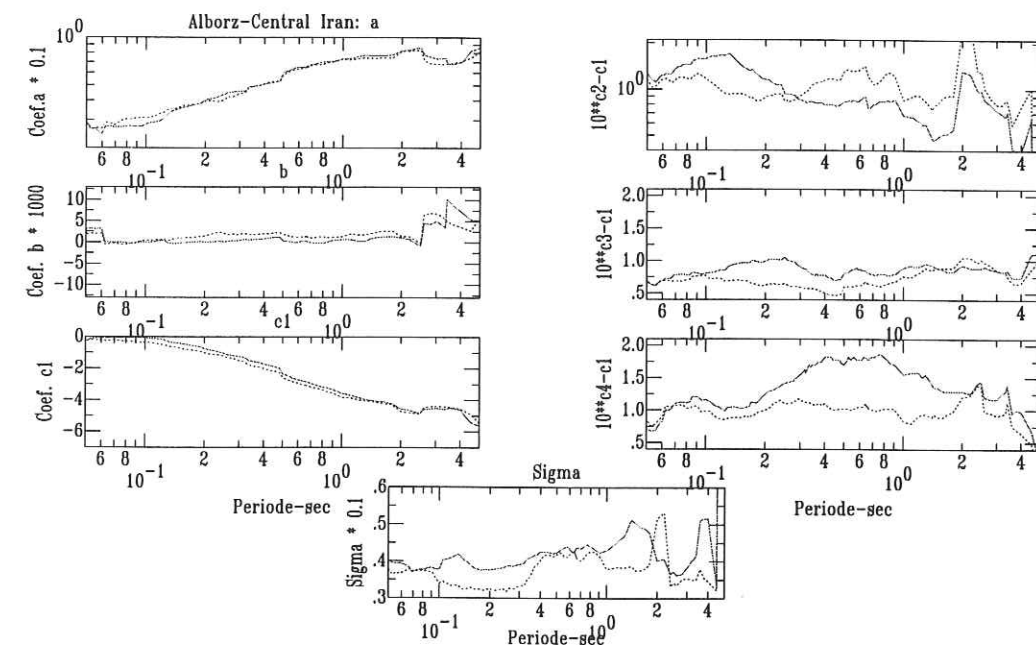


FIG. 6.13 – Coefficients of the regression (difference from $c1$) (equation 6.3) against period, for the Alborz -Central Iran data. The site coefficients of the regression against period, for the Alborz-Central Iran data are given as well; solid lines :horizontal components, dotted line: vertical components.

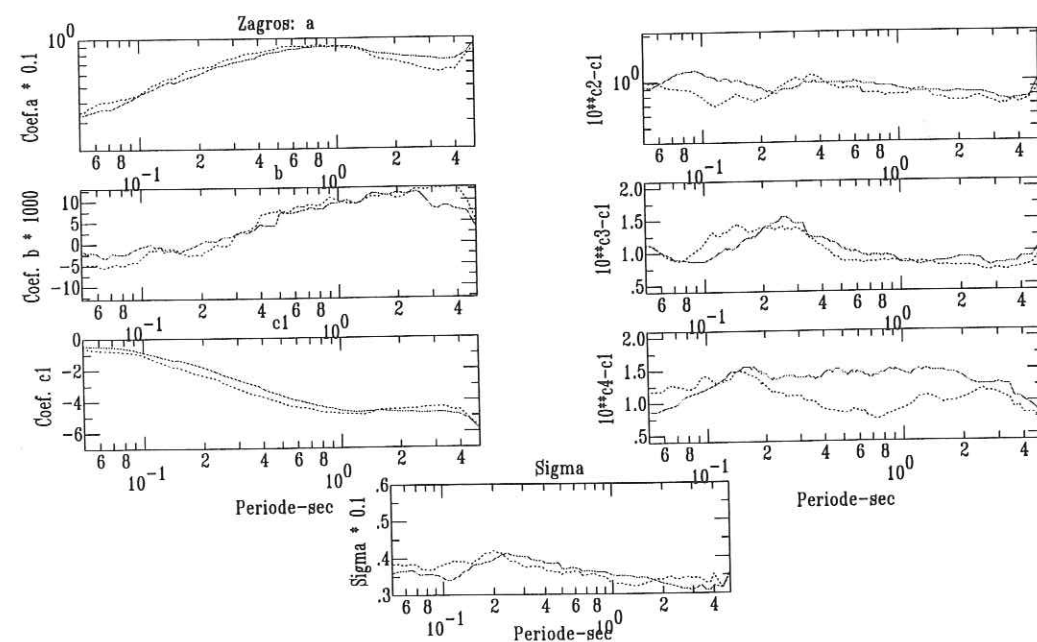


FIG. 6.14 – Coefficients of the regression (difference from c_1) (equation 6.3) against period, for the Zagros data. The site coefficients of the regression against period, for the Zagros data are given as well; solid lines: horizontal components, dotted line: vertical components.

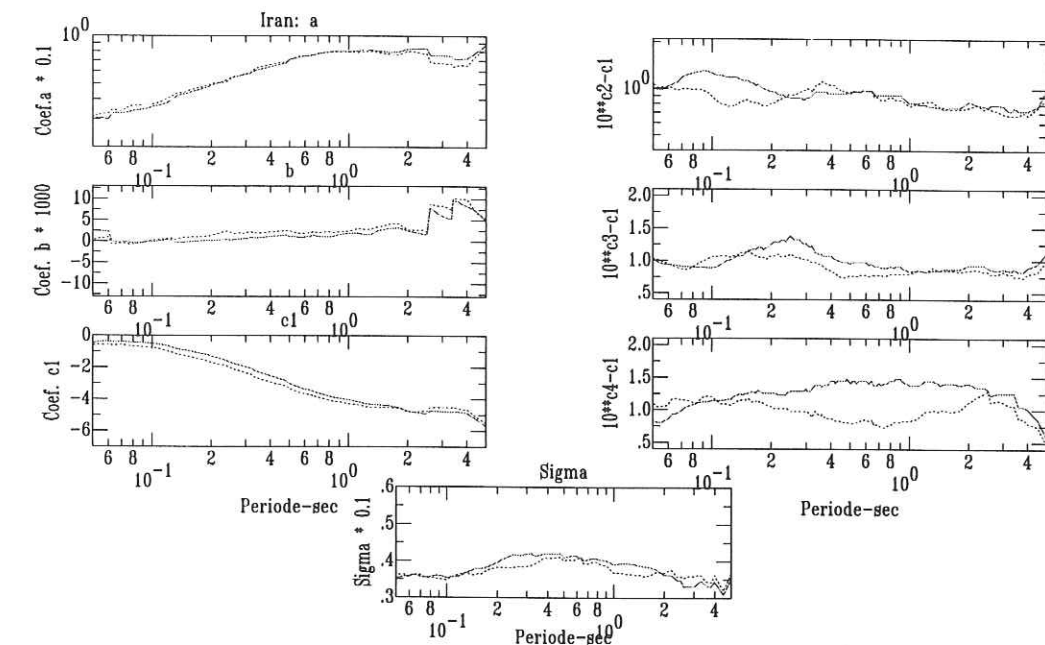


FIG. 6.15 – The coefficients of the regression (difference from c_1) (equation 6.3) against period, for the Iranian data, for $d = 1$. The site coefficients of the regression against period, for the Iranian data, for $d=1$ are given as well; solid lines: horizontal components, dotted line: vertical components.

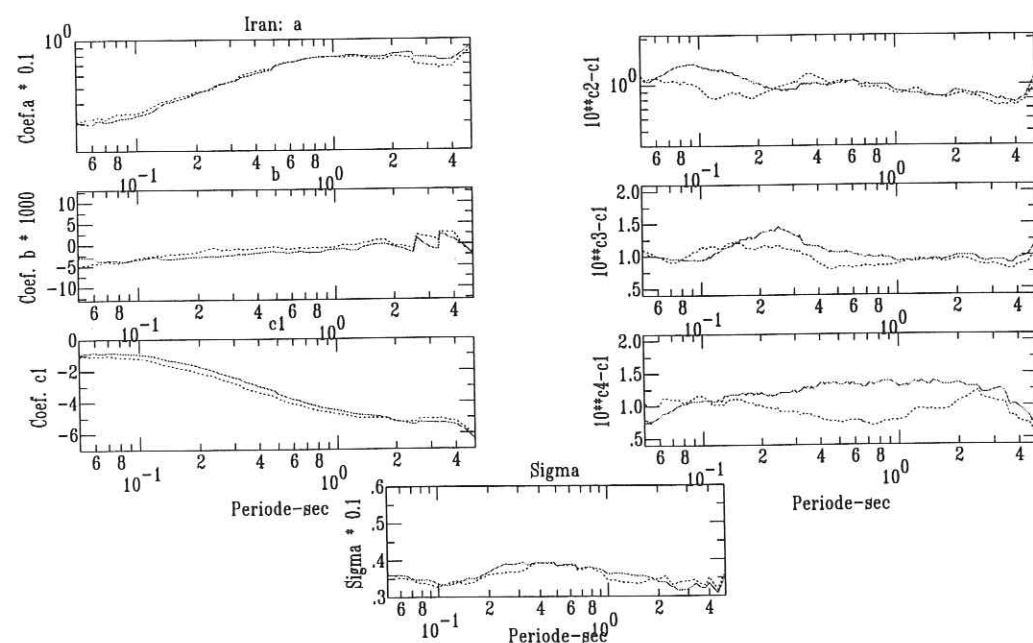


FIG. 6.16 – The coefficients of the regression (difference from $c1$) (equation 6.3) against period, for the Iranian data, for $d = 0.5$. The site coefficients of the regression against period, for the Iranian data, for $d=0.5$ are given as well; solid lines :horizontal components, dotted line: vertical components.

Differences between Alborz-Central Iran and Zagros data may be also observed in i) lower duration data for and lower magnitude (but more frequent) earthquakes in Zagros (Zaré et al 1999b) which cause probably the abnormal positive b values at high frequencies, and more rapid attenuation of strong motions in this region, and ii) the higher a values specially in middle periods in Zagros, which might be induced by the reason told for previous item. On the other hand, since there are more records in the Zagros region, site amplifications for class 3 are more evident for Zagros data (Figure 6.14) than for Alborz-Central Iran data (Figure 6.13).

6.4.3 Nonlinear effects in the Iranian strong motions?

The possible non-linear effects were looked for investigating the variation of the residuals as a function of PGA. In case of a soft soil (site class 4), a decrease of the high frequency content due to the non-linearity would be expected, which should reflect in an overestimation through prediction ($prediction > observation$). Simultaneously we would expect a reverse effect at long periods ($observation > prediction$). Such effects were looked for at several period values (0.1sec, 0.2 sec, 0.5 sec, 0.67sec, 1.0sec, 1.25sec, 2.0sec and 5.0sec). The difference between the observed values in the stations of class 4 and the predicted values (using $d = 1$ for $d \cdot \log X$) on the rock sites (for the same stations) are displayed in Figure 6.17 for the entire of the data-base. The difference between the observed and predicted values for the site class-4 are presented as well. These results show clear trends, with underestimation of spectral levels for really strong motions, and overestimation at moderate levels, whatever the period. This result was expected only at long periods, and we have no explanation for these observations at short periods.

6.5 Response and Design Spectra for Alborz-Central Iran, and Zagros areas

The coefficients for spectral values based on the whole Iranian data set are applied to estimate the response spectra of accelerations and the velocities for some typical near and far field situation on rock site conditions (Figure 6.18). The mean and mean plus one sigma values are calculated for magnitudes of $M_w 6.0$ at a distance of 10 km, and $M_w 7.4$, at distances of 20km and 100km, with $d = 0.5$ and $d = 1$. The selection of the magnitude of 7.4 was made according to the highest magnitudes occurred in Iran since the beginning of the strong motion measurements in Iran (Tabas earthquake of 1978, $M_w 7.4$).

The difference between $d=0.5$ and $d=1.0$ is clear only at short distances (10 and 20 km),

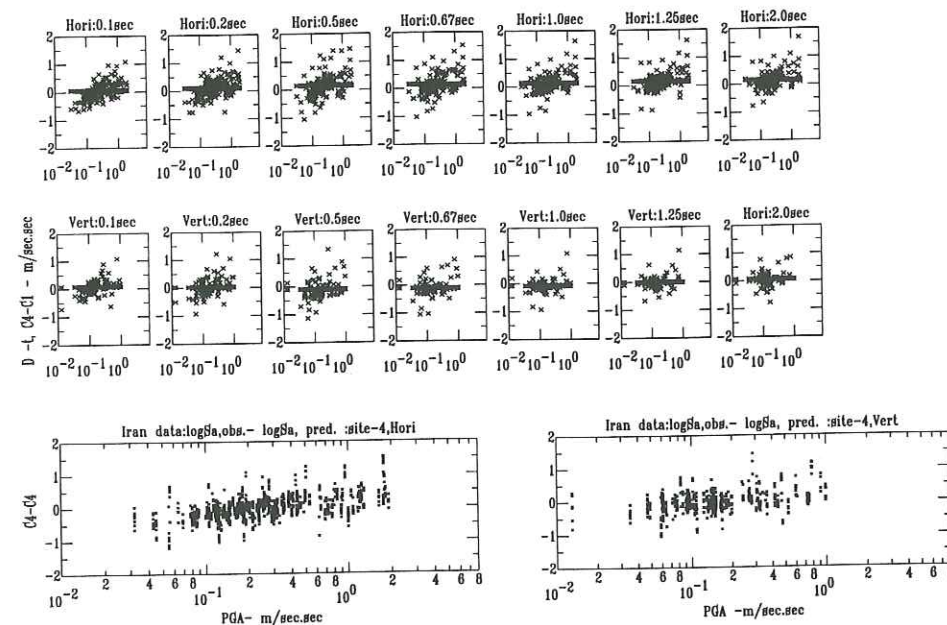


FIG. 6.17 – Difference between the observed spectral acceleration values at class-4 sites and the corresponding predicted values on rock sites, for horizontal and vertical component for the entire of the data-base. The differences between observed and predicted values on rock sites are shown as well.

with larger spectral values for $d = 1$. At 100km distance, results are almost the same. To show the results for different coefficients provided for Alborz-Central Iran, Zagros and entire of the data-base, the PGA values are looked for a magnitude of 7.0 with two different distances: The PGA values obtained with the coefficients in table-6.1 ($d = 1$), for a magnitude of 7.0 and a hypocentral distance of 20km are found to give 1.870m/sec^2 , 2.546m/sec^2 and 2.032m/sec^2 for Alborz-Central Iran, Zagros and entire of Iran data-base, respectively. With the same magnitude, and for a hypocentral distance of 50km, we obtain 0.770m/sec , 0.897m/sec and 0.833m/sec for the mentioned data-bases respectively.

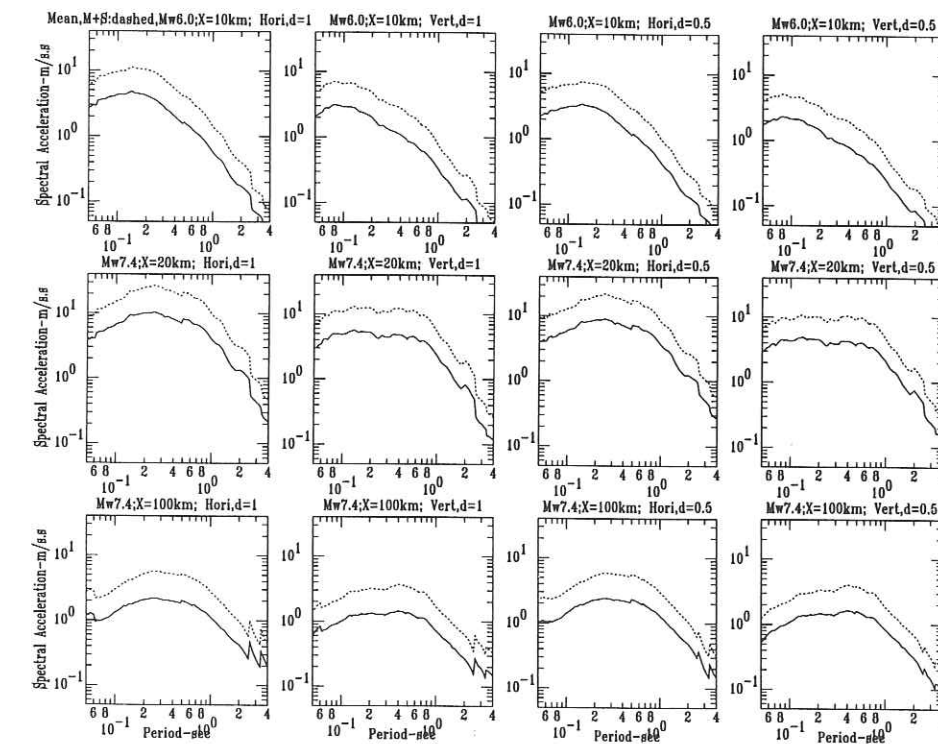


FIG. 6.18 – Representative response spectra calculated using the coefficients for the Iranian data ($d = 0.5$ and $d = 1$), for $M_w 6.0$, and 7.4 , for 10 and 20km and 100km distances, respectively: for the 3 cases (Top: $M_w=6.0$, $X=10\text{km}$), (Middle: $M_w=7.4$, $X=100\text{km}$) and (Bottom: $M_w=7.4$, $X=100$); solid line: mean and dotted line: mean $+\sigma$, two left for figures $d=1.0$ (horizontal and vertical) and two right figures for $d=0.5$ (horizontal and vertical).

Based on the results for the spectral ordinates, we will presents some response and design spectra for two different sites in Iran. The design spectra to be presented, is based on the response spectra of the records for a rock site in Tehran and a alluvial site in coastal area of the Persian Gulf (southern Zagros), with a average V_s in top 30m of 550m/sec (site class 2). To estimate the earthquake magnitude an empirical relationship for Iran is applied. This relationship is established using the fault rupture data coming form 22 earthquake faults (the events since 1336 till 1994) in Iran (Zaré 1995). This relationship predicts the moment magnitude having the fault rupture length:

$$M_w = 0.91 \cdot \ln L_R + 3.66 \quad (6.4)$$

where L_R is the rupture length in km. According to the mentioned study, in average, the rupture length might be estimated as about 0.37 of the total length of a major Iranian earthquake fault.

The main seismic sources nearby Tehran are North-Tehran fault and the Mosha fault. Taking a 120km segment of the Mosha fault and using equation 6.4, a magnitude $M_w 7.1$ is found for a rock site for northern Tehran. The intersection of the Mosha and the North-Tehran faults (in the Kalan Village in NE of Tehran) has a distance of the 35km with Tehran.

A floating earthquake scenario for Zagros belt is considered. The highest magnitude occurred in Zagros during our period of observation (Khurgu 1977) was $M_s 7.0$. The thickness of the crust is estimated to be 15km for the Coastal region in southern Zagros (based on the geological maps), therefore considering an earthquake at the bottom of the crust, such depth may be taken as the hypocentral distance. These parameters are used to select the response spectra for our site in the coastal region of Persian Gulf. The specifications of the selected records are shown in Tables 6.4 and 6.5 .

Table 6.4: Selected records to find the design spectra in Tehran:

Code BHRC	M_w	Hypocentral Distance(km)	Site
1082-1	7.4	36	1
1083-1	7.4	64	1
1084-1	7.4	5*	1
1107	6.8	61	1
1118	6.6	55	1
1139	7.1	44	1
1362-1	7.3	40	1

*:Tabas earthquake: Distance to the Fault zone

Table 6.5: Selected records to find the design spectra in a coastal area of Persian Gulf (southern Zagros):

Code BHRC	M_w	Hypocentral Distance(km)	Site
1006-1	6.1	48	2
1050-1	7.0	52	2
1058	6.1	18	2
1291-1	5.7	45	2
1491	5.7	12	2
1498	5.9	63	2
1502-9	5.9	9	2

All of the spectral acceleration and velocity values (calculated for a damping of 0.05) are normalized to PGA and PGV of each record and shown in Figure 6.19. To normalize the spectral velocities, the velocity spectral values for each record are divided by the observed PGV for that record. The mean and mean plus one sigma values are presented in Figure 6.20 and the smoothed spectra are given in Figure 6.21. According to high earthquake hazard in Iran, a conservative approach is applied to fit the smoothed spectra for these two examples (Figure 6.21). The higher spectral values are obvious for the design spectra in Tehran in longer periods, while in Zagros coast the spectra show more important values for shorter periods.

6.6 Conclusions

The attenuation of the strong ground motions in Iran was studied for the first time in this article. The regression coefficients are presented for the peak values and the spectral ordinates, which are generally in agreement with the coefficients presented by Joyner and Boore (1981), Boore et al (1993, 1994, 1997) and Fukushima et al (1995) for other regions of the world. Meanwhile the results of this study are in agreement with the Ambraseys attenuation relationships for Europe (comprising some few Iranian records) (Ambraseys 1995, Ambraseys and Simpson 1996). The conclusions are summarized below:

- The attenuation of the strong motions in Iran follows the general form of the attenuation of the strong motions in Mediterranean attenuation (Caillot 1992, using the Italian data, and Ambraseys 1995, for the European data). This general accordance might be studied more precisely if the location of the foci for the earthquakes was determined using the local networks in Iran.

- The attenuation seems to be different for, at least, two regions of Iranian plateau; the Zagros area and the Alborz-Central Iran region (Figure-3). The seismicity, strong motion duration

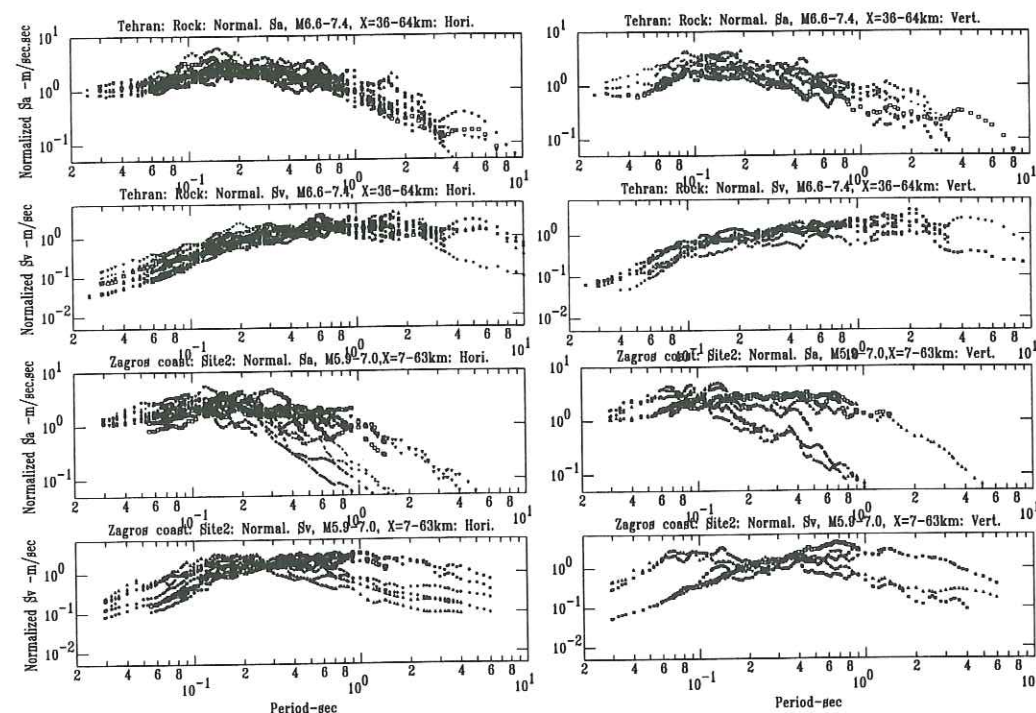


FIG. 6.19 – The normalized response spectra for a rock site in Tehran and an alluvial site in the Zagros coastal region on the Persian Gulf (specification for the spectra are given in Tables-6.4 and 6.5).

and the crust specifications seems to be one of the major factors for this evident difference. On the other hand, the response spectra for the Zagros region are rich in short periods, while the larger period amplitudes may be seen in the Alborz- Central Iran data.

- The site factors, which are obtained for 4-class site categorization of Iran, do not contribute too much except for PGD. This may come from the meteorological and topographic situation of the Iranian plateau: most of the Iranian territory is dry and arid and most of the urban areas are located on the alluvial fans, nearby the foothills.

- The attenuation term of the body waves and surface waves studied using a different coefficient for the geometric expansion term ($\log X$); the difference for these two cases was not too much, but the higher values obtained with $d = 1$ (body waves) in the near field distances (less than 20 hypocentral distances). The surface wave attenuation ($d = 0.5$) gives the higher values in greater distances. This difference may be observed especially for the Alborz-Central Iran data.

- The near-field records are still very few in the Iranian network especially for large earthquakes ($M_w > 6.0$) to investigate the near-source strong motions in Iran. The Tabas record (Tabas earthquake) and the Abbar record are the only records obtained in distances less than

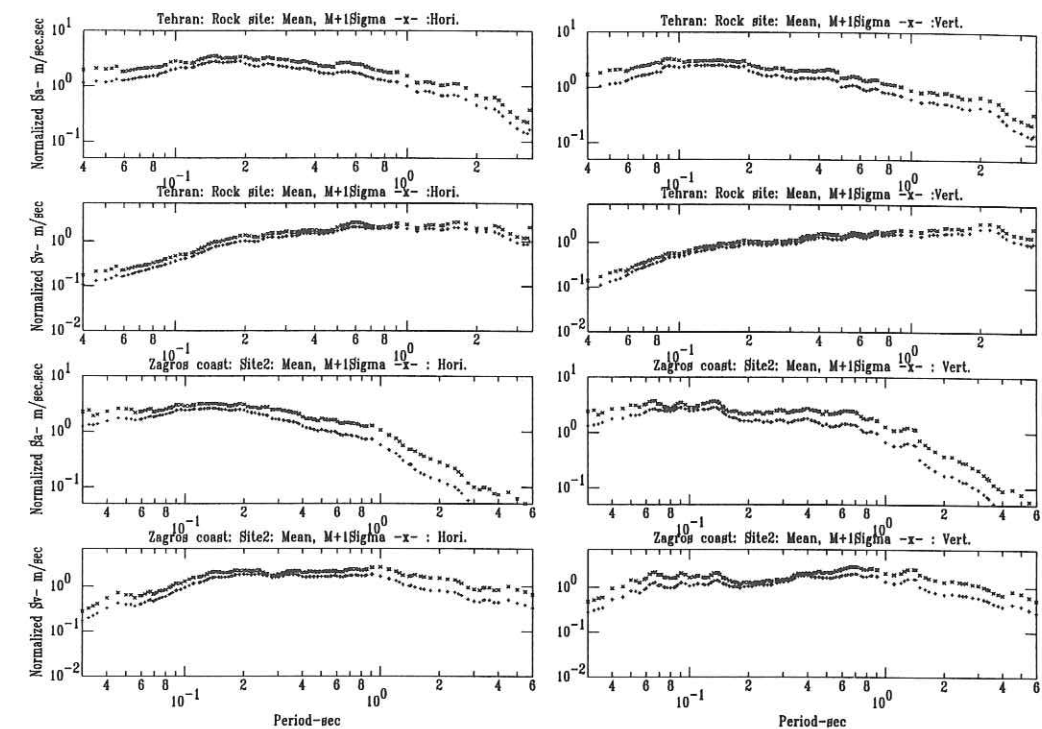


FIG. 6.20 – The mean and mean plus one sigma of the response spectra presented in Fig. 6.19

10km the surface fault ruptures for an earthquake of magnitude greater than $M_w 7.0$. This problem causes a limitation in the use of the attenuation laws presented in this paper: for the near-source cases, it is suggested to select strong motions recorded in similar situations with a deterministic approach (hypocentral distances less than about 20km, or nearest distance to the fault rupture of 10km for the sources with magnitudes greater than 7.0).

- Strong motion attenuation studies should be continued in Iran to investigate the unknown aspects of this important subject, not only to be used to seismic risk studies in Iran and its neighboring countries, but also to contribute to strong motion studies in the east-Mediterranean and European region. The main subjects suggested for future investigations are listed below;

- The attenuation parameters such as absorption coefficient (κ) and the quality factor (Q) might be investigated with more precise data to be provided with the dense network which is expanding actually in Iran. Such studies may reveal clearly the causes for the different features of the attenuation in the crust of the Iranian plateau.

- The uniform hazard spectra for Iran might be studied, based on a precise seismicity study on Iran. Furthermore, the response spectra should be classified for each defined limit for the magnitude and distance values.

- The focal depth of seismic events in Iran should be determined, *a priori*, using a dense and online seismic network (to be installed in Iran). In the absence of such data, a large uncertainty

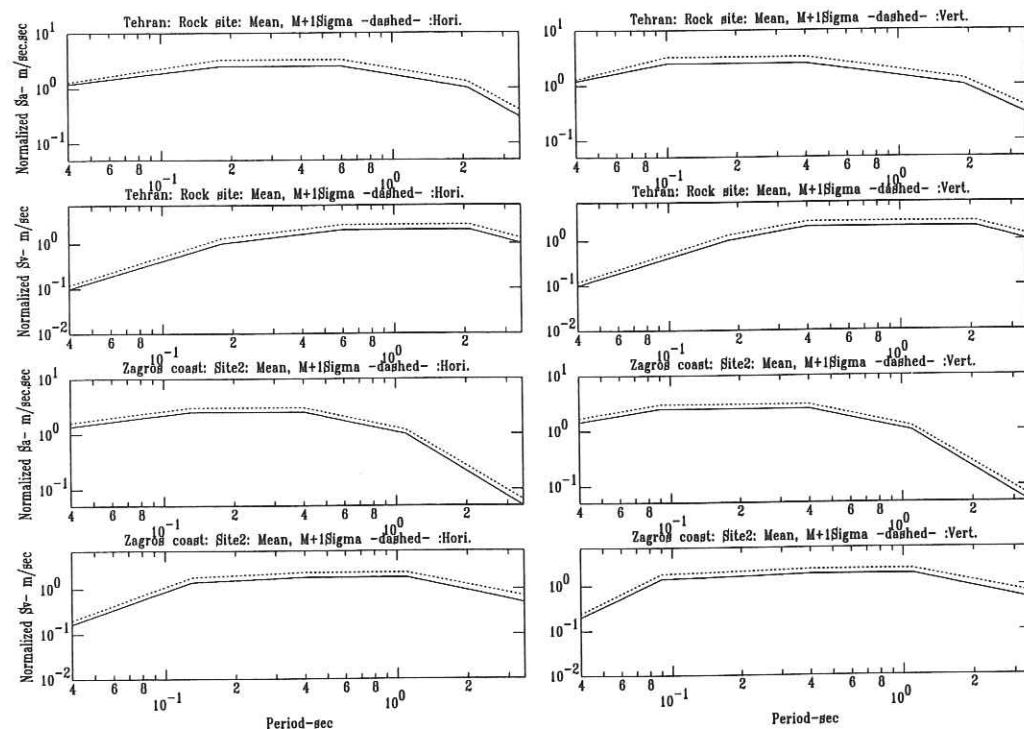


FIG. 6.21 – The smoothed spectra for the response spectra shown in Fig:6.20

will remain for the distance determinations. Such studies may help to compare the Iranian attenuation models with the other models.

- To develop the existing accelerometric network in Iran, the site and seismicity characteristics should be considered for the site selections. The installation of more instruments in the region which are sparsely populated but show high seismicity (like Makran and eastern Iran), may provide valuable information to be used everywhere.

- The studies on micro-earthquakes using the empirical Green functions for the capital of the country (Tehran), where no great and near earthquake was recorded in recent years but the seismic risk is very important, could be useful to estimate the earthquake strong motion for this city. Such estimations should be compared with real earthquakes in regions with similar condition.

- The near-source strong motions should be studied, using the dense arrays to be installed around quaternary faults. Because of the water-supply problem, most of the cities, villages and the industrial centers in Iran are located on or nearby the borders of hills and plains, where a lot of the quaternary faults are located. Such a situation highlights the need for a better understanding of the near-fault strong motion.

- Advanced source studies should be conducted in Iran. The directivity effect was an important amplification factor in the Tabas earthquake. On the other hand, the rupture modeling

may reveal the nature of the source processes in the destructive earthquakes in Iran. The first priority for such studies would be an absolute and simultaneous timing of the accelerometric network.

- The Iranian attenuation relationships should be compared with the neighboring countries relationships. The best possibility for such study is now to study the strong motions in Turkey (Anatolian plateau), which is geologically in the continuation of the Iranian plateau, and for which the strong motion data are now available.

- The site effect parameters might be studied more precisely for the attenuation models in Iran. Pairs of the stations on alluvium and nearby rock outcrop, as well as the down-hole arrays would help to understand better site effect in Iran. Using the present information, neither a more sophisticated definition of the site parameters nor the over-parameterization of the site factors would be helpful for a better understanding of the site effects. Such studies might be completed with a comparison with the similar study in highly seismic region, where strong motion and site effects are properly recorded and studied (such as Japan).

- The attenuation of macroseismic intensities might be studied more using the historical reports, which are accessible for Iran with a great civilized history and cultural heritage. Such studies may give a general view of the attenuation of the strong motion in the history (especially for the regions where strong motions are not yet recorded).

Acknowledgements

J. Christophe Gariel in IPSN (Institut de la Protection et la Surêté Nucleaire, CEA, France) kindly hosted the first author for a short term technical visit, to work on the Attenuation law within the BERSSIN team. The discussions with him, F. Cotton and B. Hernandez were useful to establish the attenuation law for Iran, that is greatly thanked. The BHRC (Building and Housing Research Center, Tehran), who released the raw strong motion records is greatly thanked. The location of the new digital instruments were provided by Mr Hossein Mizaei-Alavijeh from BHRC, which is appreciated. A financial support in France (for the first author) was provided by a French scholarship (Ministère Francais des Affaires Etrangere) and acknowledged. We acknowledge as well Poppy Buxton who has controlled the text in view point of the English orthography.

6.7 Régression en une étape

Nous avons voulu ici simplement comparer les résultats obtenus avec deux types de régressions, une et deux étapes. Nous avons pour cela utilisé le logiciel STATISTICA. L'ensemble des données (déjà étudiés avec les régressions dans deux étapes, discuté avant dans ce chapitre) ont été utilisées dans la régression dans une étape avec la même relation déjà utilisée:

$$\log A = a \cdot M_w + b \cdot X - d \cdot \log X + c_i \cdot S_i + \sigma \cdot P \quad (6.5)$$

Les valeurs des coefficients de cette relation sont présentées dans le tableau 6.6 pour les paramètres différents (A_{rms} , e_a , A_{max} , V_{max} , D_{max});

Tableau 6.6: Les valeurs des coefficients de la régression en appliquant la relation 6.5 pour les paramètres différents;

Paramètre/comp.	a	b	c1	c2	c3	c4	Sigma	R
A_{rms} , Vertical	0.320	0.0029	-1.675	-1.650	-1.655	-1.647	0.327	0.566
A_{rms} , Horizontal	0.343	0.0027	-1.576	-1.466	-1.537	-1.610	0.339	0.607
e_a , Vertical	0.767	-0.0005	-4.233	-4.208	-4.198	-4.120	0.564	0.415
e_a , Horizontal	0.807	-0.0005	-4.104	-3.913	-3.982	-4.072	0.567	0.535
A_{max} , Vertical	0.307	0.0025	-0.937	-1.951	-0.948	-0.902	0.330	0.638
A_{max} , Horizontal	0.311	0.0023	-0.749	-0.685	-0.729	-0.715	0.328	0.682
V_{max} , Vertical	0.508	0.0040	-3.550	-3.631	-3.567	-3.517	0.325	0.689
V_{max} , Horizontal	0.501	0.0035	-3.216	-3.238	-3.221	-3.135	0.331	0.828
D_{max} , Vertical	0.750	0.0038	-5.787	-5.947	-5.887	-5.877	0.352	0.769
D_{max} , Horizontal	0.766	0.0023	-5.627	-5.738	-5.686	-5.491	0.353	0.781

Les résidus des entre valeurs prédites et valeurs observées sont présentés dans les Figures 6.22 à 6.26. Les valeurs prédites des paramètres A_{rms} , e_a , A_{max} , V_{max} et D_{max} , en utilisant les coefficients de tableau 6.6 avec la relation 6.5 (la régression dans une étape) ont été comparés avec les résultats de la méthode de la régression dans deux étapes (pour les mêmes paramètres et le même jeu de données; l'ensemble des données iraniennes; Figures 6.27 à 6.31). Ces comparaisons montrent que les deux régressions prédisent les valeurs comparatives pour une gamme de distance de 20-80km. A moins de 20km, la régression en une étape sous-estime les paramètres de mouvements forts par rapport à la régression en deux étapes. Cette situation est inversée aux distances supérieures à 80km. De plus, les estimations de V_{max} et D_{max} avec la régression en une étape, montrent une augmentation avec la distance, évolué de la distance de 80km qui

est illogique. Cette perturbation peut être considérée comme due à l'insuffisance des données à grande distance. Cela peut donc montrer que la méthode de régression en une étape est plus sensible à l'homogénéité de la distribution des données avec la distance, alors que cette condition est moins évidente pour la régression en deux étapes (Figures 6.27 à 6.31).

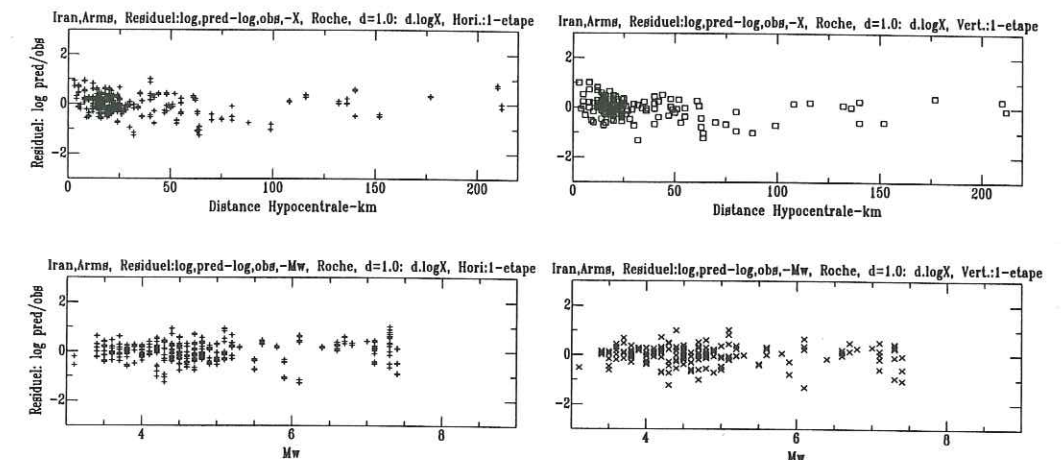


FIG. 6.22 – Le résiduel (\log prédit - \log observé) de A_{rms} en fonction de la distance hypocentrale et de la magnitude, pour l'ensemble des données iraniennes avec $d=1.0$

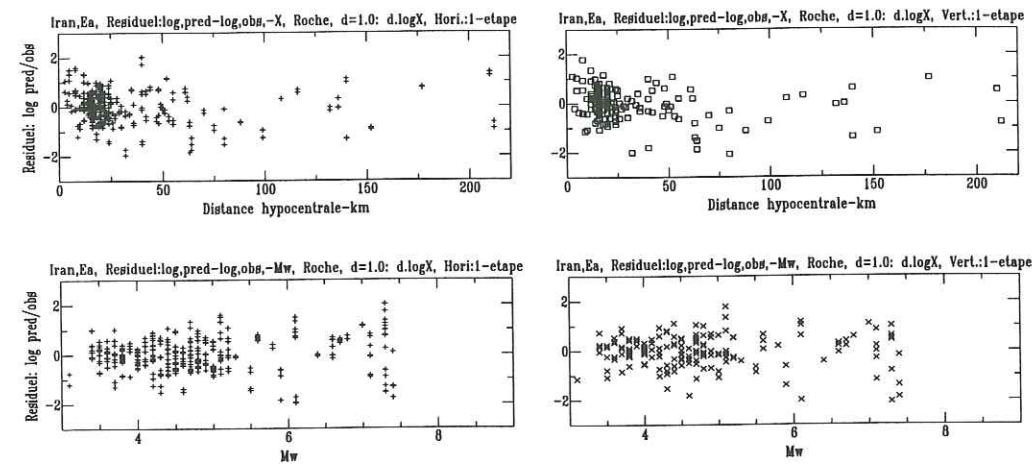


FIG. 6.23 – Le résiduel (log prédit- log observé) de e_a en fonction de la distance hypocentrale et de la magnitude, pour l'ensemble des données iraniennes avec $d=1.0$

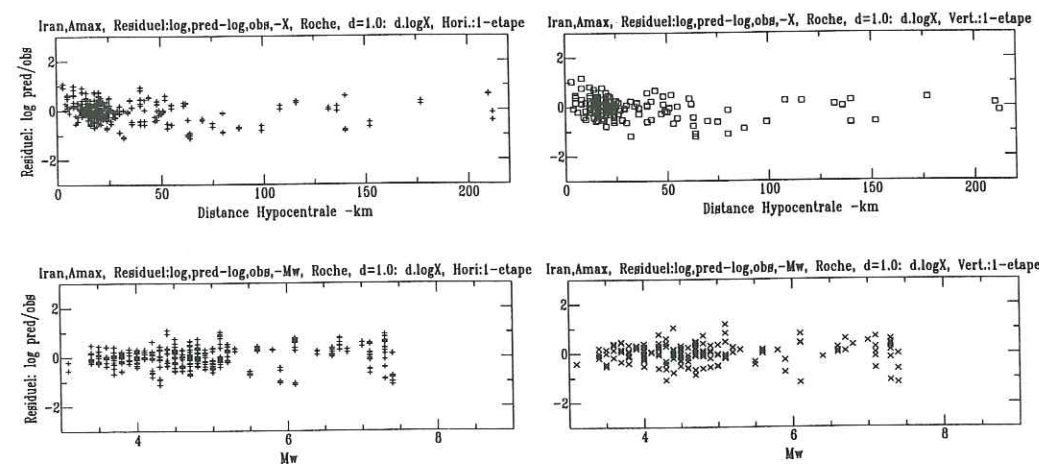


FIG. 6.24 – Le résiduel (log prédit- log observé) de A_{max} en fonction de la distance hypocentrale et de la magnitude, pour l'ensemble des données iraniennes avec $d=1.0$

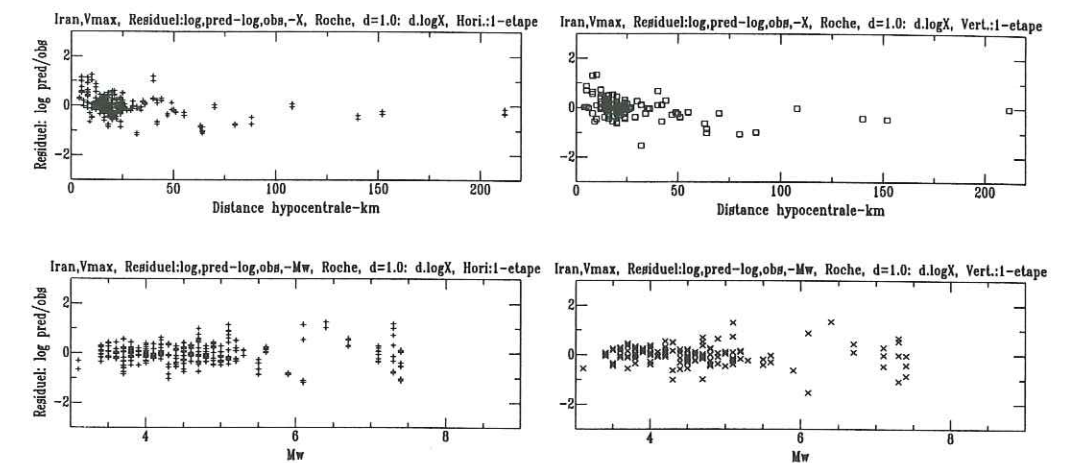


FIG. 6.25 – Le résiduel (log prédit- log observé) de V_{max} en fonction de la distance hypocentrale et de la magnitude, pour l'ensemble des données iraniennes avec $d=1.0$

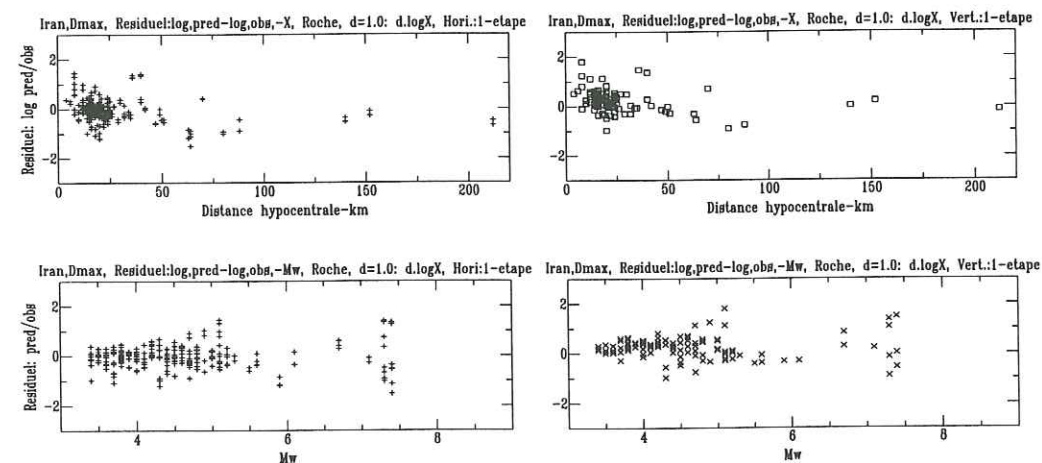


FIG. 6.26 – Le résiduel (log prédit- log observé) de D_{max} en fonction de la distance hypocentrale et de la magnitude, pour l'ensemble des données iraniennes avec $d=1.0$

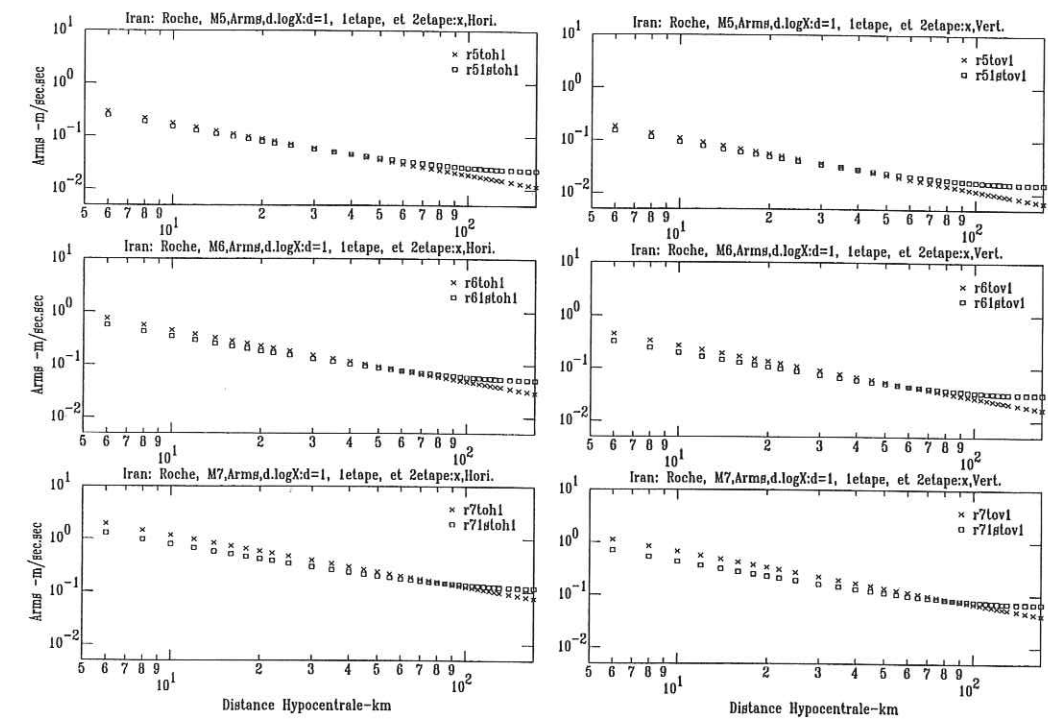


FIG. 6.27 – L'atténuation de A_{rms} en fonction de la distance hypocentrale pour les magnitudes de 5.0, 6.0 et 7.0, basé sur les résultats de la régression en une-étape (les rectangulaires) et en deux-étapes (les croix) pour l'ensemble des données iraniennes.

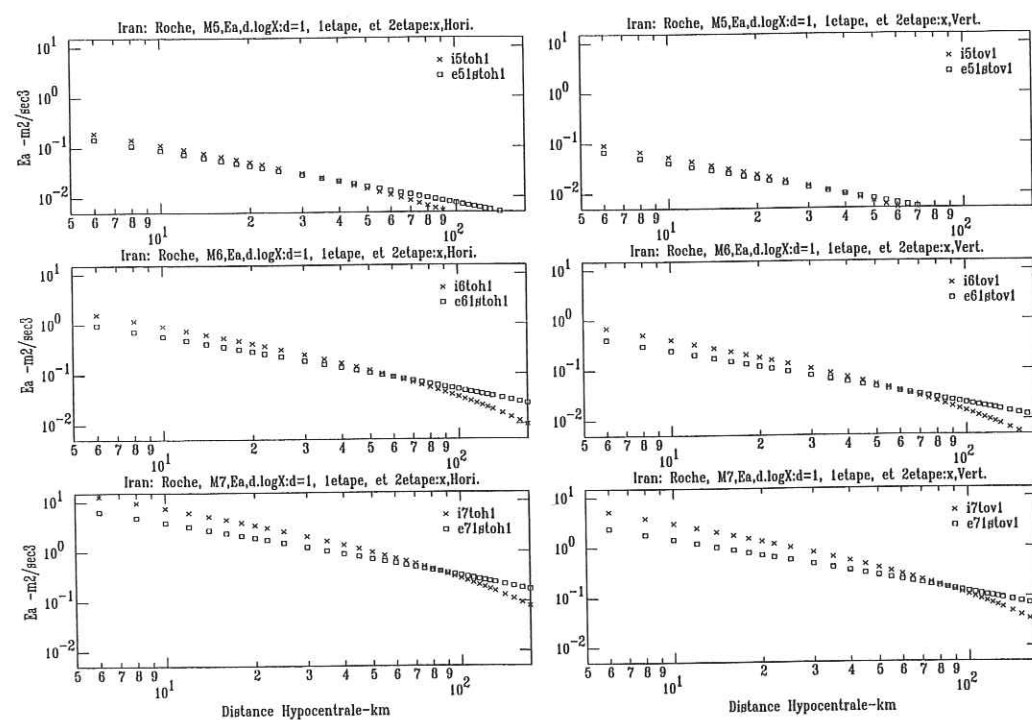


FIG. 6.28 – L'atténuation de e_a en fonction de la distance hypocentrale pour les magnitudes de 5.0, 6.0 et 7.0, basé sur les résultats de la régression en une-étape (les rectangulaires) et en deux-étapes (les croix) pour l'ensemble des données iraniennes.

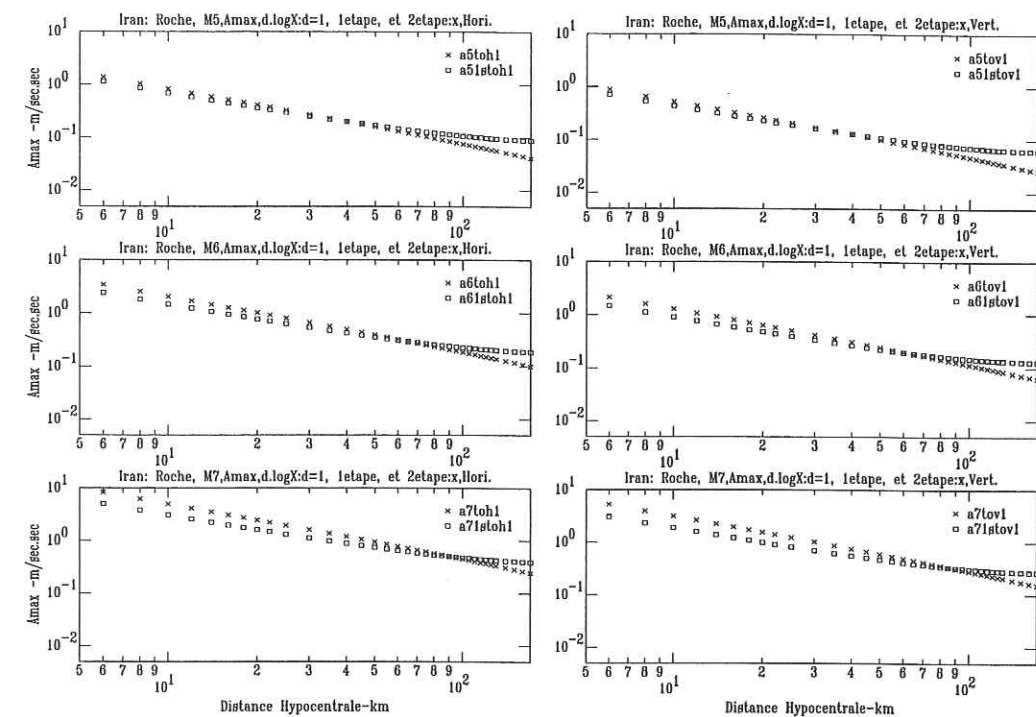


FIG. 6.29 – L'atténuation de A_{max} en fonction de la distance hypocentrale pour les magnitudes de 5.0, 6.0 et 7.0, basé sur les résultats de la régression en une étape (les rectangulaires) et en deux-étapes (les croix) pour l'ensemble des données iraniennes.

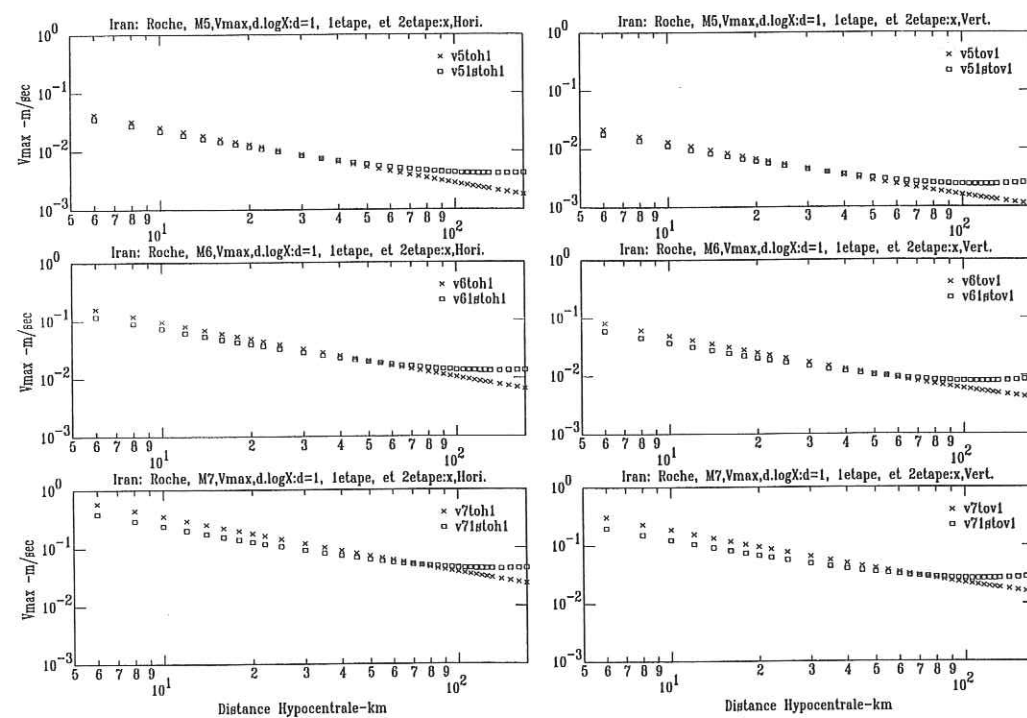


FIG. 6.30 – L'atténuation de V_{max} en fonction de la distance hypocentrale pour les magnitudes de 5.0, 6.0 et 7.0, basé sur les résultats de la régression en une-étape (les rectangulaires) et en deux-étapes (les croix) pour l'ensemble des données iraniennes.

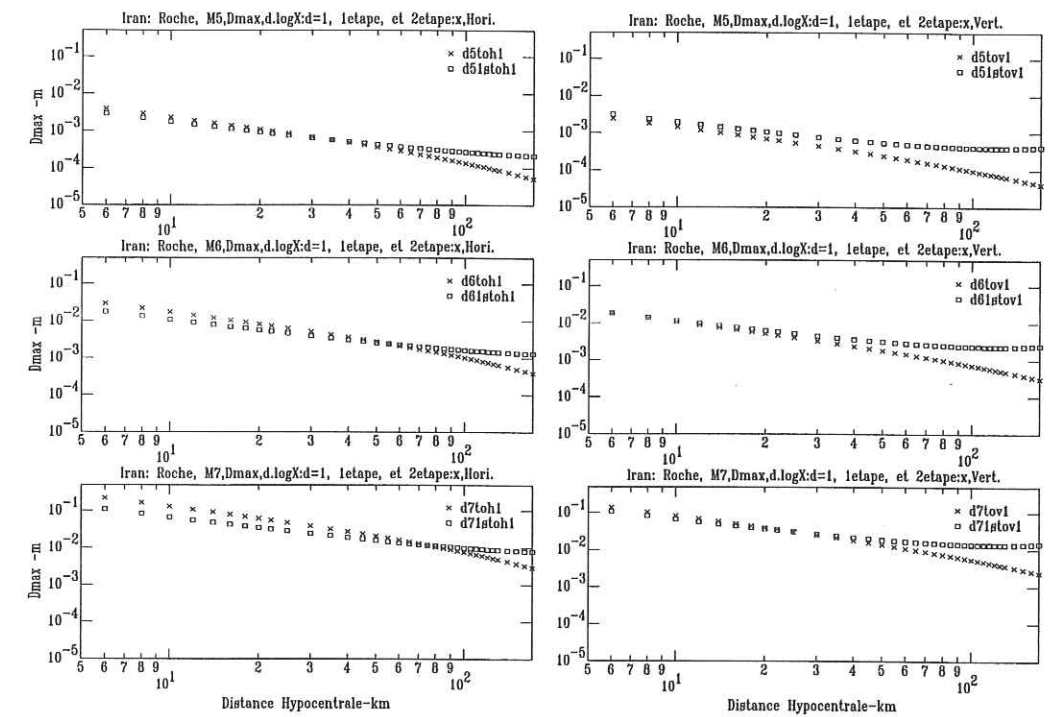


FIG. 6.31 – L'atténuation de D_{max} en fonction de la distance hypocentrale pour les magnitudes de 5.0, 6.0 et 7.0, basé sur les résultats de la régression en une-étape (les rectangulaires) et en deux-étapes (les croix) pour l'ensemble des données iraniennes.

Une autre forme de cette relation est étudiée qui ne se sert plus de l'atténuation anélastique et de l'expansion géométrique, mais en cherchant la meilleur décroissance "logarithmique" avec la distance:

$$\log A = a \cdot M_w - b \cdot \log X + c_i \cdot S_i + \sigma \cdot P \quad (6.6)$$

Les résultats des calculs en utilisant cette formule-la sont présentés dans le tableau 6.7:

Tableau 6.7: Valeurs des coefficients de régression en appliquant la relation 6.6;

Paramètre/comp.	a	b	c1	c2	c3	c4	Sigma	R
A_{rms} , Vertical	0.308	0.581	-2.081	-2.048	-2.047	-2.081	0.320	0.407
A_{rms} , Horizontal	0.319	0.539	-1.992	-1.863	-1.929	-2.023	0.327	0.489
e_a , Vertical	0.728	0.889	-4.275	-4.240	-4.236	-4.187	0.570	0.162
e_a , Horizontal	0.752	0.768	-4.168	-3.959	-4.036	-4.167	0.570	0.226
A_{max} , Vertical	0.286	0.571	-1.327	-1.324	-1.317	-1.317	0.324	0.398
A_{max} , Horizontal	0.281	0.547	-1.135	-0.050	-1.092	-1.129	0.317	0.479
V_{max} , Vertical	0.500	0.447	-4.118	-4.172	-4.107	-4.108	0.317	0.487
V_{max} , Horizontal	0.480	0.434	-3.759	-3.750	-3.732	-3.708	0.319	0.539
D_{max} , Vertical	0.722	0.357	-6.393	-6.501	-6.453	-6.510	0.339	0.509
D_{max} , Horizontal	0.729	0.471	-6.080	-6.148	-6.105	-5.978	0.343	0.411

6.8 Les études sur la nonlinéarité possible dans les données iraniennes

La possibilité des effets de nonlinéarité sous forte accélération a été analysée par l'études des résidus des valeurs maximales de l'accélération (A_{max}). Ces résidus logarithmiques (logarithme des valeurs observées moins logarithme des valeurs prédites) sont représentés en fonction des valeurs de A_{max} observées pour les 4 sites différents et pour les deux types de régression (1 et 2 étapes)(Figures 6.32 à 6.35). Ces figures montrent une claire augmentation des résidus avec l'augmentation des valeurs de A_{max} observés, et une décroissance avec l'augmentation des A_{max} prédits. Cet effet est contraire à l'effet attendu, qui devrait être une décroissance de l'amplification à forte accélération. Cette observation peut s'interpréter comme la conséquence de la situation géologique du pays: la plupart des sites accélérométriques sont situés sur les alluvions raides et secs et sur les 25 ans d'existence du réseau accélérométrique iranien aucun

séismes ne s'est produit dans les régions côtières (où se trouvent les sols mous). Selon ces résultats, il faut donc insister encore sur la nécessité d'être prudent dans l'applications des lois d'atténuation présentées dans cette étude; pour les site à faible distance de forts séisme.

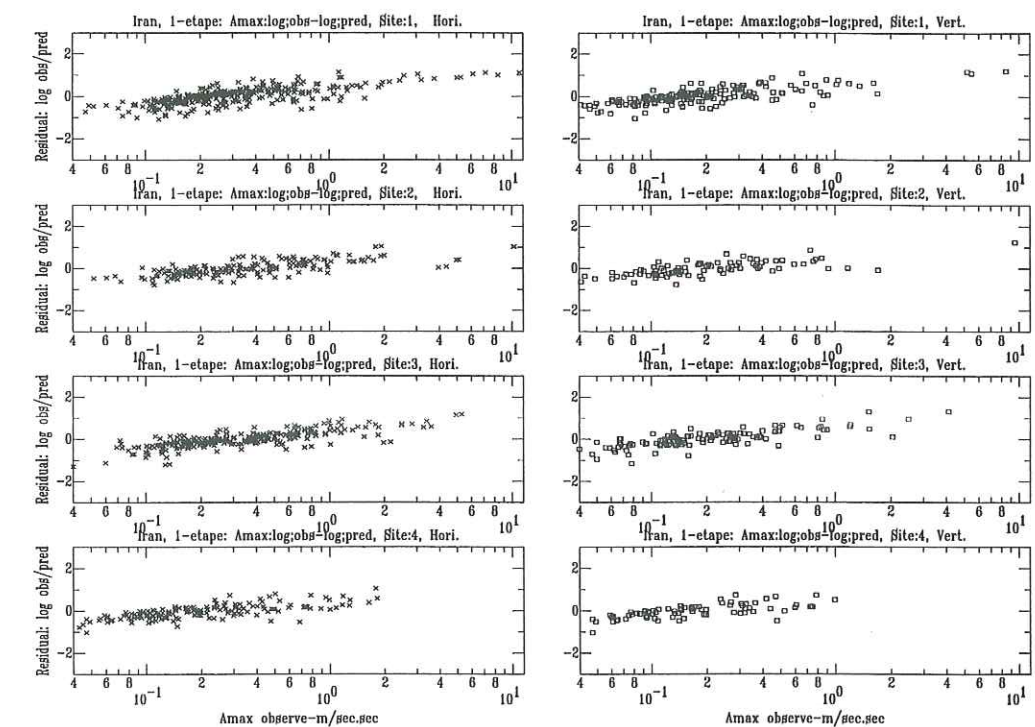


FIG. 6.32 – Les résiduels (log observé - log prédit) de A_{max} en fonction de A_{max} observé pour les catégories différents des sites en utilisant de la régression en une-étape, pour l'ensemble des données iraniennes

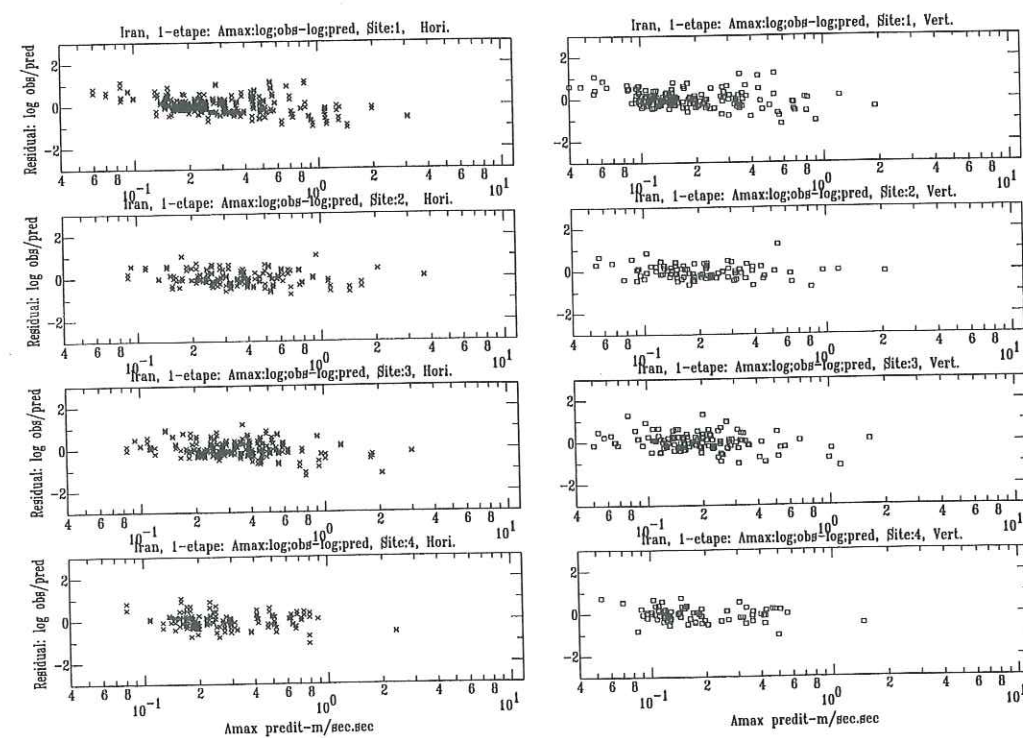


FIG. 6.33 – Les résiduels (\log observé - \log prédit) de A_{max} en fonction de A_{max} prédit pour les catégories différents des sites en utilisant de la régression en une-étape, pour l'ensemble des données iraniennes

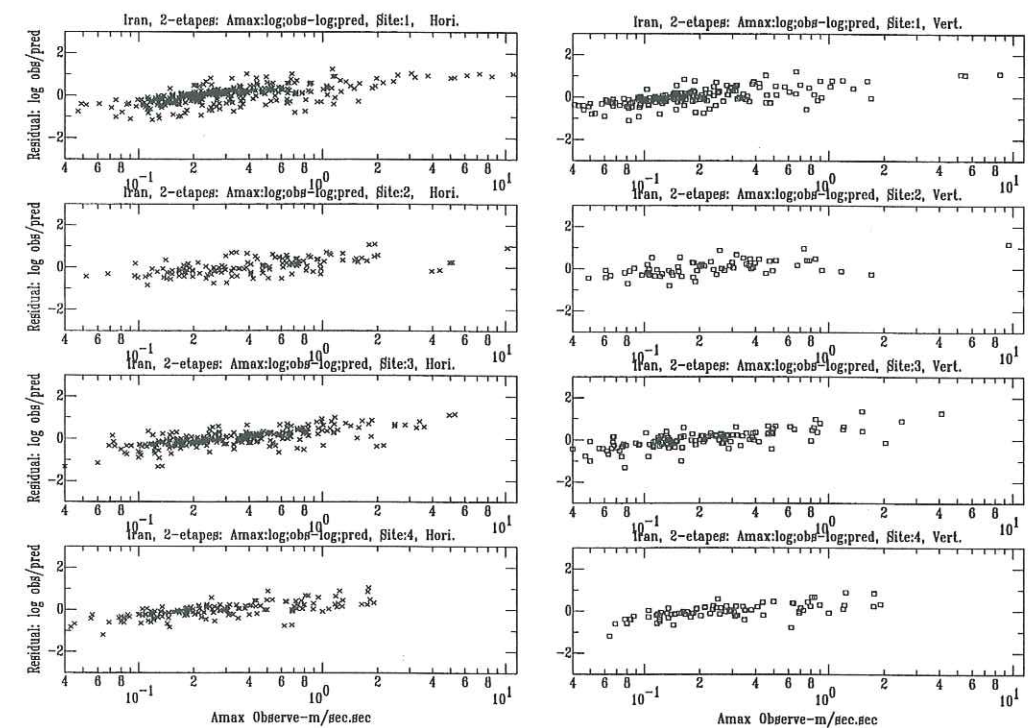


FIG. 6.34 – Les résiduels (\log observé - \log prédit) de A_{max} en fonction de A_{max} observé pour les catégories différents des sites en utilisant de la régression en deux-étapes, pour l'ensemble des données iraniennes

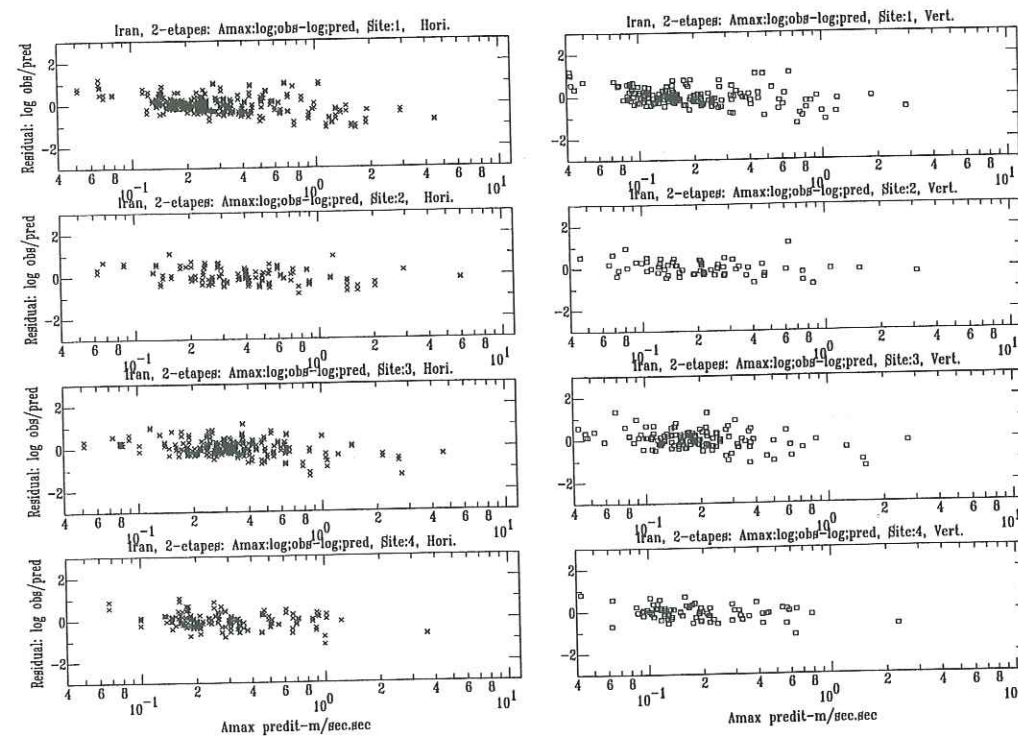


FIG. 6.35 – Les résiduels (\log observé - \log prédit) de A_{max} en fonction de A_{max} prédit pour les catégories différents des sites en utilisant de la régression en deux-étapes, pour l'ensemble des données iraniennes

Pour examiner si cette dérive non-linéaire inverse à l'effet attendu était due à une mauvaise prise en compte de l'expansion géométrique, nous avons influé sur les lois d'atténuation des ordonnées spectrales en modifiant le coefficient d , et en étudiant les variations des résidus lorsque d varie de 0.5 à 3.0. Les écarts-type pour ces estimations sont présentés sur la Figure 6.36; on peut conclure que, quelque soit la période, le plus faible écarte-type est obtenu pour $d=0.5$. Ce résultat peut indiquer que les grands résidus pour les forts valeurs de A_{max} n'ont rien à voir avec la valeur de d , et ne contribuent donc pas d'une manière représentative à la forme de la loi d'atténuation.

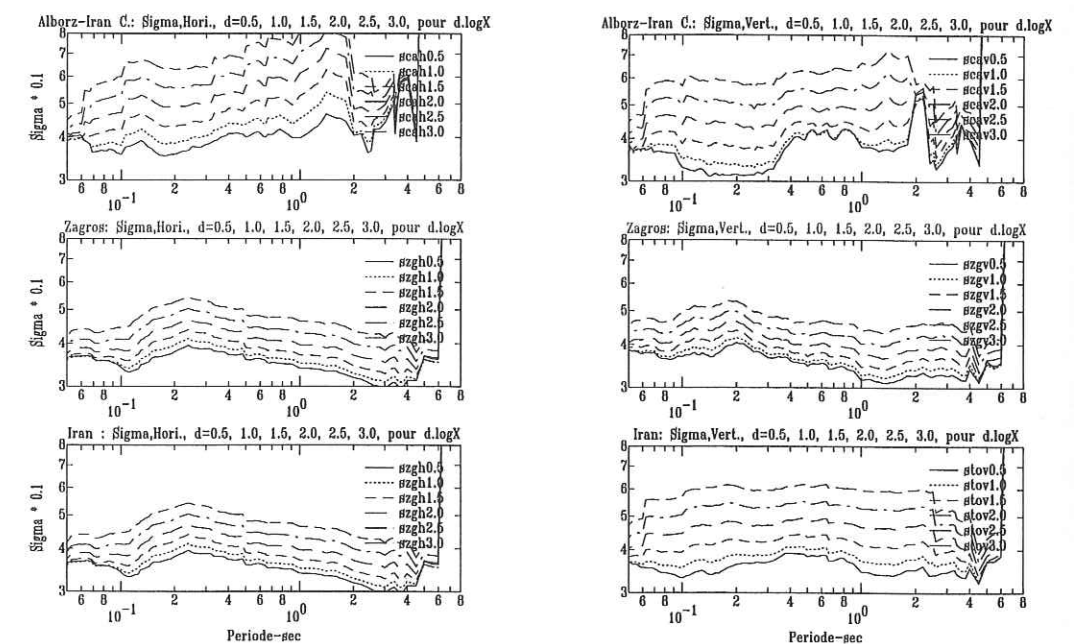


FIG. 6.36 – Les valeurs différents de Sigma avec d de 0.5 à 3.0 pour les régressions en fonction des périodes différents. Les résultats ont présentés pour les régions de l'Alborz-Iran Central, le Zagros, et l'ensemble des données iraniennes

Appendix 6.1: The data-base used in this study.

No	Site	record	Mw	R (km)	Duration (H1) sec	Duration (V) sec	Duration (H2) sec	Arms (H1) m/sec2	Arms (V) m/sec2	Arms (H2) m/sec2	Ea (H1) m/sec3	Ea (V) m/sec3	Ea (H2) m/sec3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	PGV (H1) m/sec	PGV (V) m/sec	PGV (H2) m/sec	PGD (H1) m	PGD (V) m	PGD (H2) m
1	2	1012-00	4.5	64	1.53	5.22	1.56	1400	0320	1200	0340	0058	0240	390	157	300						
2	2	1006-01	6.1	48	15.04	20.25	11.38	2300	1100	3300	8700	2900	14000	863	417	1287	0629	0329	0847			
3	2	1006-02	5.2	40	16.33	16.27	14.43	0430	0370	0530	0330	0250	0450	167	125	260						
4	1	1007-00	6.1	80	16.02	17.51	18.23	0410	0260	0350	0290	0140	0250	217	094	168						
5	1	1008-00	6.1	56	25.60	20.13	22.57	0370	0360	0360	0390	0280	0320	148	137	121						
6	4	1013-00	4.4	34	5.83	10.53	7.72	0890	0210	0630	0510	0051	0340	428	102	192						
7	1	1009-00	4.8	48	11.19	17.34	14.70	0660	0200	0390	0540	0074	0250	357	077	154						
8	4	1026-01	4.1	60	3.64	3.78	6.71	0890	0610	0370	0320	0150	0100	505	286	251						
9	3	1014-04	5.4	32	14.53	11.88	15.17	1800	1100	1600	5300	1700	4500	669	471	796						
10	3	1024-00	4.6	6	2.76	2.56	2.63	7400	3700	8000	17000	4000	19000	3270	1533	3595	0717	0234	0968			
11	2	1034-01	3.9	26	2.38	1.92	2.35	1300	0970	1300	0430	0200	0460	432	316	537	0119	0084	0144			
12	2	1034-02	4.6	12	6.8	2.58	1.88	6600	1900	2900	3300	0980	1800	1997	845	1022						
13	1	1040-03	4.7	88	1.28	1.58	1.49	1200	1400	1200	0200	0320	0220	437	452	495	0090	0170	0169	000460	001400	001300
14	1	1043-0	6.4	10	11.20	7.82	10.58	3100	3900	3500	12000	13000	14000	1150	1700	1570	0110	0028	0065			
15	2	1047-08	6.4	11	1.1	.60	.13	2.8000	4200	22000	9800	1200	7200	5.117	1.167	4.982	0742	0223	0571			
16	2	1047-09	4.8	9	.30	.55	.52	5800	2200	4900	1100	0290	1400	1750	674	1559	0164	0053	0160	000370	000234	000560
17	2	1047-10	5.1	5	.66	.58	.71	2100	2500	2500	0320	0390	0510	602	920	978	0122	0199	0066	000270	000190	000680
18	2	1046-01	7.3	48	16.07	20.10	20.40	1600	0890	1300	4900	1000	3600	891	455	685						
19	2	1046-02	5.5	47	7.61	9.57	7.02	1400	0430	1300	1600	0190	1300	718	212	408						
20	1	1049-01	4.4	3	7.05	9.72	7.38	0880	0530	1000	0610	0300	0870	402	153	337						
21	1	1049-02	4.4	19	6.10	8.74	5.78	0350	0190	0580	0081	0036	0220	119	082	166						
22	1	1049-03	4.8	14	6.11	8.35	6.42	0260	0150	0380	0046	0020	0110	081	053	134						
23	2	1050-01	7.0	52	21.56	27.32	17.98	2200	1100	3000	1200	3700	17000	973	379	1504	0556	0275	0768			
24	1	1052-00	7.0	71	7.75	7.44	7.55	0750	0520	0740	0490	0220	0460	184	149	266						
25	1	1054-01	6.1	7	2.78	3.18	2.70	2.5000	1.6000	1.9000	18.0000	8.8000	11.0000	7.200	5.200	6.150	4600	5400	3800	010000	010200	003200
26	1	1055-00	6.1	32	14.00	12.59	13.59	0490	0280	0560	0370	0110	0480	155	093	180						
27	2	1058-00	6.1	18	3.95	5.08	4.16	2300	1300	2300	2200	1000	2500	981	493	816						
28	4	1059-00	6.1	21	1.62	5.32	3.02	1800	0480	1300	0600	0130	0540	685	477	623						
29	1	1056-05	4.9	15	.44	2.41	1.75	1800	0420	0790	0150	0047	0120	649	219	370	0072	0059	0084			
30	1	1060-02	4.8	20	3.21	2.64	5.02	0340	0510	0310	0040	0076	0054	127	168	159						
31	1	1080-08	5.0	19	3.39	5.24	3.06	2200	1600	2900	1900	1400	2900	1056	780	1587						
32	2	1092-01	4.4	30	2.56	5.90	1.70	0700	0210	1200	0140	0028	0260	442	183	640	0066	0028	0072			
33	1	1080-10	4.9	15	1.19	1.01	.96	2400	3100	3300	0780	1100	1200	720	1019	1061						
34	1	1080-11	5.0	28	1.39	1.32	2.64	1100	1100	0670	0180	0180	0130	513	572	360						
35	1	1080-12	4.3	30	.56	1.12	.53	2800	1100	2800	0500	0140	0460	1.171	417	1.137						
36	2	1094-01	4.9	12	7.63	7.05	4.71	0840	0390	1700	0600	0120	1600	408	160	826						
37	1	1082-01	7.4	36	34.01	30.20	34.91	4900	3600	5000	9.0000	4.2000	9.7000	3.204	1.618	3.757	1758	1183	2400	040002	027052	059408
38	1	1083-01	7.4	64	21.58	24.34	22.56	2700	2100	2600	1.7000	1.2000	1.7000	980	870	940	0980	0760	1140	001900	001600	002300
39	1	1084-01	7.4	27	16.56	14.88	18.30	1.9000	1.4000	1.8000	66.0000	32.0000	66.0000	11.030	8.480	8.410	1.1300	3600	9700	900000	120000	355000
40	3	1096-00	7.4	140	27.64	31.10	26.36	1500	0470	1500	7000	0750	8800	1795	159	581	0457	0145	0318			
41	3	1090-02	7.4	234	26.66	25.52	27.62	1100	0780	1200	3700	1700	4600	321	246	394						
42	1	1082-06	4.7	53	.97	2.34	1.04	1700	0740	1300	0310	0140	0210	676	390	440						
43	1	1103-01	4.5	22	3.59	4.88	2.39	0560	0360	0890	0120	0070	0210	226	301	421	0048	0033	0077			
44	1	1104-02	4.5	42	.76	3.79	5.26	1700	0450	0550	0260	0086	0180	500	280	355	0204	0069	0164			
45	1	1093-02	4.2	75	3.89	4.67	4.30	0570	0480	0660	0130	0120	0210	323	188	234						
46	1	1103-03	4.9	20	3.50	8.28	2.67	1400	0530	2200	0770	0250	1500	659	343	1052	0167	0066	0308			
47	3	1098-03	6.2	20	4.38	5.42	4.20	1100	0720	1000	0570	0310	0470	556	287	517	0140	0072	0127			
48	1	1096-01	6.1	5	.57	.78	.88	2600	2500	2600	0440	0540	0630	710	754	807	0110	0108	0452			
49	1	1096-02	4.7	5	1.87	1.98	.26	0480	0440	3000	0047	0043	0270	252	226	568	0030	0030	0077			
50	1	1097-02	4.7	5	.22	.75	3.91	3300	1300	0430	0270	0140	0081	812	454	359	0091	0138	0052			
51	1	1103-09	4.5	21	4.42	5.86	4.24	0590	0410	1100	0170	0110	0600	277	176	853	0057	0048	0166			
52	3	1102-00	6.8	135	7.88	10.32	10.43	1300	0350	0930	1400	0140	1000	375	151	278						
53	3	1106-00	6.8	80	17.33	13.34	15.20	0820	0770	1000	1300	0880	1700	353	384	486						
54	1	1107-00	6.8	61	13.59	18.51	13.16	0680	0450	0820	0700	0420	0990	276	165	362						
55	4	1109-00	6.8	96	15.98	20.62	12.30	0610	0360	0860	0300	1000	221	193	314							
56	2	1113-00	6.8	80	11.65	21.73	13.86	1800	0640	1500	4100	1000	3300	689	304	663						
57	1	1103-11	5.1	18	6.10	7.43	5.52	1200	1000	2000	1000	0840	2400	553	459	780						
58	1	1103-12	5.5	55	10.01	11.30	9.94	1100	0760	1300	1300	0730	1900	858	419	872	0186	0084	0254			
59	2	1125-02	5.1	25	3.14	3.20	1.44	1100	0920	2200	0460	0300	0810	608	476	790						
60	3	1117-00	6.6	96	20.90	25.88	23.09	0510	0270	0510	0590	0210	0660	281	124	208						
61	1	1118-00	6.6	55	11.28	10.35	10.05	0790	0800	1200	0770	0750	1500	313	319	420						
62	2	1121-00	6.6	72	16.91	21.67	17.17	1800	0910	1900	5800	2000	6800	734	370	744						
63	1	1124-00	6.6	116	14.40	21.11	17.11	0470	0330	0380	0350	0260	0270	166	126	140						
64	3	1130-02	6.6	184	13.18	14.40	14.15	0660	0390	0740	0650	0240	0850	262	119	261						
65	1	1132-01	6.6	132	25.45	28.40	23.03	0660	0410	0800	1200	0530	1600	245	166	297						
66	2																					

No	Site	record	Mw	R (km)	Duratio n (H1) sec	Duratio n (H2) sec	Arms (H1) m/sec2	Arms (H2) m/sec2	Ea (H1) m/sec2	Ea (H2) m/sec2	PGA (H1) m/sec2	PGA (H2) m/sec2	PGV (H1) m/sec	PGV (H2) m/sec	PGD (H1) m	PGD (V) (H1) m	PGD (H2) (H1) m						
126	1	1319-02	4.3	64	88	1.25	1.42	3300	2000	2000	1100	0560	0610	1132	662	684	0234	0123	0158	000775	000493	000977	
127	3	1305-00	5.0	4	4.69	7.69	4.54	2500	0950	2300	3300	0780	2600	1009	488	733	0393	0142	0257	001783	000638	001193	
128	1	1307-01	4.6	24	3.17	3.85	3.91	1000	0630	1000	0370	0170	0800	535	311	580	0137	0057	00083	000443	000233	000309	
129	4	1303-00	4.2	10	5.20	5.57	6.09	3400	1200	2200	6900	0950	3300	1286	322	796	0582	0141	0353	003016	000703	001842	
130	1	1300-01	5.3	8	8.07	9.28	7.48	1700	1500	2600	2500	0200	0120	0110	097	115	107			005998	005025	003816	
131	1	1300-03	4.7	20	9.03	9.67	8.06	0330	0330	0340	0110	0300	0997	0280	0130	105	251	116					
132	1	1351-00	7.3	210	14.51	11.66	12.76	0250	0470	0300	2600	14000	23000	1860	900	1340	1540	0760	1170	039000	028000	030000	
133	3	1353-1	7.3	76	18.04	26.46	24.50	3600	2200	5900	37000	8000	74000	1282	728	1906							
134	4	1354-00	7.3	80	22.73	23.61	19.13	3800	1700	5900	2100	17000	7600	14000	892	737	888	1000	0473	0884			
135	4	1355-00	7.3	68	29.06	27.86	27.28	2300	1700	4600	2000	12000	60000	1080	750	1760	1350	0730	3630	071000	041500	155000	
136	4	1357A-1	7.3	96	33.96	32.62	27.72	2700	1800	4600	2100	19000	1300	12000	1173	303	727						
137	4	1359-00	7.3	100	18.40	24.69	26.25	3000	0700	2100	1000	3000	24000	4382	1712	3958	0937	0389	0941				
138	2	1360-00	7.3	12	1.61	2.23	1.83	15000	4900	11000	38000	5900	24000	4382	1712	3958	0937	0389	0941				
139	3	1361-00	7.3	176	32.43	33.47	33.27	1200	0730	1600	4800	2000	9700	499	388	951							
140	1	1362-1	7.3	40	31.92	35.96	35.06	8300	9100	5900	25000	33000	14000	5260	5480	5030	3800	4840	4360	163000	204000	203000	
141	4	1363-1	7.3	224	15.14	14.59	15.14	1400	0830	1400	3500	1100	3500	460	280	350	0710	0280	0500	015000	007000	015000	
142	1	1364-0	7.3	80	35.84	40.92	39.96	2100	1100	1500	18000	5700	10000	1250	510	600	1460	0510	0950	063000	039000	040000	
143	4	1365-1	7.3	195	8.28	8.98	9.02	1100	0500	0880	1000	0250	0770	300	140	189	133						
144	4	1366-0	7.3	212	17.92	14.74	18.58	0440	0480	0380	0390	0370	0800	2900	400	320	440	0420	0480	0620	008800	013000	016000
145	4	1369-0	7.3	198	14.42	12.10	13.84	1000	1000	1400	1800	0600	0290	130	190	170	0068	0124	0105	001300	001600	001500	
146	4	1370-2	7.3	207	16.20	15.74	17.52	0290	0590	0390	0150	0200	0300	0220	350	130	120	0350	0150	0140	005900	002500	002400
147	1	1371-2	7.3	177	11.84	13.94	13.96	0950	0440	0370	7800	3000	7600	720	440	770	0610	0250	0600	010500	005700	012200	
148	4	1372-0	7.3	140	26.64	33.74	22.60	1600	0900	0700	0470	0110	0520	271	146	209							
149	4	1373-00	7.3	209	8.85	6.81	8.55	0690	0340	0350	0380	0050	0120	111	237	135							
150	4	1375-02	4.2	45	9.00	9.70	9.01	0290	0220	0460	0850	0310	0047	0150	388	165	248						
151	1	1393-02	4.2	99	1.45	2.02	1.92	1400	0460	0850	0440	0600	0390	601	698	470	0174	0117	0128	000609	000227	000314	
152	1	1393-04	4.8	24	4.22	3.30	4.45	0970	1300	0890	0440	0600	0390	601	698	470	0174	0117	0128	000609	000227	000314	
153	2	1397-00	4.4	75	2.56	5.97	2.34	0410	0240	0540	0409	0039	0077	322	257	341	0040	0042	0064	000594	000329	001034	
154	3	1398-01	4.4	8	1.58	1.58	1.58	0600	0520	0220	0320	0140	0027	0070	243	132	183						
155	3	1398-02	4.5	38	4.46	5.11	6.06	0520	0220	0320	0140	0027	0070	243	132	183							
156	1	1393-07	4.5	36	4.28	10.87	7.37	4.39	1800	0400	0750	0510	0130	0270	738	303	320						
157	3	1398-05	4.6	20	1.46	7.37	1.95	1600	0210	0870	0230	0055	0160	374	162	320							
158	1	1393-09	4.7	15	1.87	3.06	1.72	1000	0360	0950	0220	0044	0170	677	203	323							
159	3	1398-08	4.4	20	2.60	6.40	3.94	4100	1300	3300	4900	1100	4800	2000	9700	499	388						
160	2	1377-01	5.2	16	8.5	7.07	2.55	2300	0210	1000	0490	0036	0280	437	161	331							
161	3	1382-01	4.2	45	4.27	4.44	5.07	0650	0300	1100	0200	0045	0280	437	161	331							
162	3	1382-02	4.2	45	4.27	4.44	5.07	0650	0300	1100	0200	0045	0280	437	161	331							
163	2	1377-02	4.3	24	2.85	5.32	3.32	2100	0620	1500	1300	0400	0049	0100	0041	151	075	100					
164	3	1382-08	4.5	7	1.02	5.31	2.08	0660	0160	0420	0018	0090	0010	0041	151	075	100						
165	3	1382-11	4.5	40	1.05	1.57	1.53	2800	0980	0300	0840	0790	0150	0780	582	186	553	0125	0030	0100	000100	000043	000090
166	2	1397-08	4.4	28	5.40	7.21	10.01	1100	0250	0330	0051	0023	0035	170	150	175	0041	0024	0028	000088	000048	000106	
167	4	1449-0	4.6	84	3.36	3.28	2.98	0370	0370	0370	0370	0370	0370	0370	0370	0370	0370	0370	0370	0370	0370	0370	
168	3	1420-01	4.4	16	6.5	1.17	1.10	0790	0360	0740	0045	0017	0067	222	149	238	0041	0027	0046	000408	000071	000419	
169	3	1420-02	4.4	16	6.5	1.17	1.10	0790	0360	0740	0045	0017	0067	222	149	238	0041	0027	0046	000408	000071	000419	
170	3	1512-01	4.5	16	5.51	4.19	2.49	0890	1200	1000	0480	0720	0280	435	650	438	0175	0016	0037	000141	000120	000302	
171	1	1505-00	4.4	24	7.02	8.02	4.43	0960	0084	0091	0004	0003	0004	068	032	052	0119	0035	0055	000653	000114	000209	
172	2	1504-01	4.4	16	3.74	3.95	4.24	0970	0420	0630	0320	0093	0190	420	109	258	0119	0035	0055	000653	000114	000209	
173	2	1491-00	4.7	12	3.08	4.71	4.57	0420	0270	0610	0120	0046	0190	191	105	193	0045	0028	0064	000289	000114	000317	
174	1	1492-01	4.2	16	3.80	4.18	4.86	0590	0320	0380	0140	0049	0090	261	201	115	0043	0026	0031	000115	000089	000091	
175	2	1503-01	4.3	12	4.42	3.62	5.10	0490	0410	0380	0120	0058	0084	216	107	138	0062	0019	0032	000436	000119	000192	
176	2	1494-02	4.3	12	3.71	5.09	5.58	0610	0250	0330	0150	0035	0068	216	107	138	0062	0019	0032	000436	000119	000192	
177	2	1500-01	3.5	8	2.74	4.03	3.92	0510	0230	0320	0100	0079	0023	0044	178	104	109	0029	0011	0016	000080	000069	000080
178	2	1500-02	3.2	8	2.90	3.16	2.87	0240	0160	0280	0018	0009	0024	095	078	166	0130	0009	0022	000027	000053	000522	
179	2	1500-03	4.3	8	3.15	4.05	2.67	1600	0740	0210	0950	0250	1300	728	272	613	0130	0055	0160	000517	000572	000702	
180	2	1500-04	4.3	8	3.15	4.05	2.67	1600	0740	0210	0950	0250	1300	728	272	613	0130	0055	0160	000517	000572	000702	
181	1	1492-02	4.8	34	7.42	9.80	9.26	0650	0810	1700	1800	0460	1600	641	358	748	0239	0089	0094	000378	000200	000383	
182	2	1500-04	4.8	12	6.02	6.33	5.08	1600	0810	1700	1800	0460	1600	641	358	748	0239	0089	0094	000378	000200	000383	
183	1	1492-03	4.6	16	6.67	6.33	5.61	0490	0220	0550	0150	0033	0190	145	080	223	0048	0028	0054	000808	000536	000390	
184	2	1494-02	4.8	20	8.64	11.06	9.34	0470	0310	0420	0220	0120	0180	239	143	150	0101	0058	0049	000422	000255	000337	
185	2	1494-03	4.6	12	3.53	4.15	3.09	1400	0760	1400	1500	0270	0930	1111	299	730	0130	0059	0151	000707	000227	000500	
186	2	1																					

No	Site	record	Mw	R (km)	Duration (H1) sec	Duration (V) sec	Duration (H2) sec	Arms (H1) m/sec2	Arms (V) m/sec2	Arms (H2) m/sec2	Ea (H1) m/sec3	Ea (V) m/sec3	Ea (H2) m/sec3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	PGV (H1) m/sec	PGV (V) m/sec	PGV (H2) m/sec	PGD (H1) m	PGD (V) m	PGD (H2) m
376	2	1594-00	4.2	20	6.20	6.88	4.61	.0320	.0190	.0380	.0073	.0027	.0075	.160	.141	.233	.0038	.0017	.0061	.000530	.000185	.000306
377	3	1543-00	4.8	82	8.46	9.85	10.29	.0330	.0160	.0320	.0100	.0029	.0120	.120	.068	.162	.0034	.0011	.0042	.000160	.000123	.000256
378	1	1590-02	4.6	70	9.2	2.35	2.02	.0970	.0560	.0570	.0096	.0081	.0073	.215	.246	.251	.0028	.0028	.0036	.000062	.000044	.000063
379	3	1633-01	4.8	80	8.47	10.11	10.34	.0330	.0160	.0320	.0100	.0029	.0120	.120	.067	.161	.0038	.0029	.0046	.000547	.000736	.000470
380	1	1533-02	5.0	20	5.99	8.59	7.34	.0440	.0220	.0390	.0130	.0046	.0120	.209	.105	.163	.0105	.0046	.0062	.000990	.000715	.000551
381	4	1552-00	4.1	18	3.40	6.09	5.15	.0450	.0210	.0300	.0077	.0031	.0051	.308	.133	.181	.0054	.0024	.0049	.000259	.000063	.000225
382	4	1635-01	4.1	18	3.41	6.09	5.16	.0450	.0210	.0300	.0077	.0031	.0051	.306	.133	.181	.0055	.0025	.0050	.000224	.000046	.000246
383	3	1620-01	4.0	20	1.91	3.88	1.36	.2500	.1000	.2100	.1400	.0460	.0690	1.125	.468	.680	.0252	.0079	.0147	.000669	.000138	.000468
384	3	1576-00	3.5	12	4.56	3.56	3.46	.0250	.0350	.0390	.0033	.0048	.0058	.150	.158	.228	.0019	.0018	.0035	.000069	.000091	.000099
385	3	1626-00	5.1	14	4.34	5.19	4.38	.1100	.0730	.0900	.0570	.0310	.0390	.650	.392	.408	.0173	.0062	.0093	.000881	.001230	.000569
386	3	1542-00	3.6	12	8.2	1.50	1.50	.0420	.0240	.0280	.0016	.0009	.0013	.207	.077	.091	.0022	.0011	.0017	.000064	.000053	.000064
387	4	1635-02	4.0	20	5.34	4.76	5.91	.0230	.0290	.0180	.0033	.0044	.0021	.171	.181	.078	.0041	.0029	.0032	.000218	.000062	.000123
388	2	1557-00	3.8	20	5.34	6.05	6.36	.0210	.0130	.0150	.0027	.0011	.0015	.133	.043	.061	.0026	.0005	.0019	.000094	.000069	.000103
389	3	1620-02	4.1	20	1.88	4.04	1.35	.1400	.0580	.1300	.0440	.0150	.0230	.643	.230	.385	.0104	.0023	.0050	.000285	.000071	.000151
390	3	1620-03	3.7	18	3.11	6.52	5.78	.0330	.0140	.0140	.0037	.0014	.0012	.155	.067	.069	.0040	.0007	.0015	.000107	.000063	.000066
391	3	1620-04	3.9	18	2.12	5.68	4.70	.0940	.0240	.0290	.0210	.0037	.0044	.331	.135	.148	.0072	.0017	.0041	.000175	.000070	.000128
392	3	1631-02	3.7	16	6.05	8.30	2.99	.0100	.0077	.0230	.0007	.0005	.0017	.074	.035	.129	.0010	.0007	.0031	.000092	.000022	.000172
393	4	1569-00	4.4	20	4.06	9.52	5.88	.0220	.0069	.0140	.0022	.0005	.0013	.126	.049	.069	.0025	.0014	.0018	.000282	.000170	.000173
394	3	1549-01	3.7	12	1.95	.89	1.44	.0550	.1000	.1300	.0066	.0099	.0280	.170	.261	.478	.0035	.0040	.0096	.000140	.000150	.000296
395	3	1549-02	3.5	12	2.44	2.16	1.64	.0270	.0340	.0370	.0020	.0028	.0025	.136	.164	.164	.0017	.0023	.0032	.000050	.000054	.000075
396	2	1647-01	3.7	12	2.66	2.81	2.63	.1200	.0790	.1200	.0400	.0200	.0390	.463	.270	.398	.0085	.0036	.0093	.000314	.000531	.000487
397	3	1540-00	4.9	16	11.73	12.96	11.52	.0310	.0096	.0330	.0120	.0013	.0140	.122	.031	.102	.0065	.0018	.0078	.001116	.000367	.001055
398	3	1637-01	5.2	16	11.73	12.94	11.51	.0310	.0097	.0330	.0120	.0013	.0140	.123	.031	.103	.0066	.0019	.0079	.001165	.000400	.001141
399	1	1537-00	5.2	25	12.47	13.01	12.53	.0470	.0210	.0170	.0300	.0065	.0041	.208	.125	.109	.0077	.0045	.0039	.001175	.000989	.000529
400	3	1541-00	5.2	20	9.69	12.47	9.18	.0330	.0150	.0490	.0120	.0030	.0250	.170	.083	.236	.0078	.0032	.0205	.001287	.000874	.002960
401	1	1615-01	5.2	42	10.34	11.02	8.90	.0230	.0180	.0290	.0063	.0039	.0084	.086	.086	.212	.0051	.0034	.0066	.000621	.000801	.000753
402	3	1632-01	5.2	52	10.27	11.94	10.36	.0210	.0096	.0210	.0051	.0012	.0051	.101	.040	.086	.0076	.0042	.0061	.001379	.001151	.000657
403	1	1564-02	4.9	8	1.48	2.58	1.23	.1000	.0650	.1500	.0180	.0120	.0290	.525	.244	.563	.0102	.0028	.0087	.000278	.000116	.000173
404	3	1620-05	3.4	20	1.74	4.63	3.96	.0330	.0110	.0120	.0021	.0006	.0006	.149	.050	.073	.0023	.0004	.0010	.000048	.000044	.000038
405	1	1590-03	3.6	15	3.24	3.73	3.42	.0450	.0340	.0370	.0072	.0047	.0052	.186	.159	.191	.0025	.0019	.0026	.000084	.000108	.000071
406	1	1538-00	3.6	16	4.65	8.27	2.17	.0320	.0200	.0720	.0053	.0035	.0120	.268	.151	.360	.0029	.0015	.0047	.000099	.000081	.000147
407	1	1586-00	5.1	21	7.99	8.65	9.28	.0350	.0190	.0250	.0110	.0035	.0063	.166	.082	.113	.0048	.0052	.0032	.000397	.001299	.000869
408	1	1625-02	5.1	49	6.59	8.14	6.51	.0460	.0320	.0530	.0150	.0095	.0200	.179	.177	.285	.0051	.0057	.0095	.000526	.001078	.000864
409	4	1539-00	5.6	70	8.65	10.86	9.78	.0490	.0370	.0400	.0230	.0160	.0180	.191	.168	.147	.0071	.0044	.0071	.000527	.000188	.000588
410	1	1559-00	4.2	15	4.21	6.48	3.83	.0560	.0260	.0500	.0150	.0050	.0100	.391	.193	.393	.0054	.0029	.0046	.000319	.000229	.000201
411	4	1544-00	4.4	16	3.50	5.16	4.07	.0880	.0430	.0630	.0300	.0110	.0180	.434	.198	.228	.0118	.0040	.0061	.000548	.000137	.000593
412	3	1560-01	4.5	19	2.79	3.69	4.51	.3100	.3000	.2400	.3000	.3600	.2900	1.167	1.518	.992	.0354	.0225	.0259	.001918	.001304	.001570
413	3	1572-00	4.5	45	8.78	6.09	5.89	.0320	.0180	.0610	.0100	.0023	.0250	.146	.071	.190	.0037	.0018	.0067	.000283	.000175	.000399
414	3	1560-02	4.0	20	3.44	4.71	3.20	.0400	.0310	.0440	.0060	.0050	.0069	.171	.134	.165	.0057	.0031	.0040	.000188	.000088	.000127
415	3	1560-03	3.8	18	2.84	3.71	3.63	.0430	.0330	.0320	.0059	.0044	.0041	.195	.183	.143	.0054	.0032	.0028	.000171	.000077	.000089
416	3	1560-04	5.0	18	6.72	4.23	4.84	.1400	.0300	.2200	.1500	.2000	.2600	.789	.816	1.058	.0249	.0145	.0258	.001655	.000663	.001243
417	3	1560-05	3.8	8	3.95	3.82	4.09	.0370	.0350	.0390	.0062	.0053	.0070	.197	.143	.171	.0051	.0024	.0029	.000175	.000104	.000087
418	1	1590-04	3.5	14	2.74	2.64	2.80	.0450	.0630	.0490	.0052	.0170	.0074	.241	.293	.267	.0039	.0033	.0023	.000078	.000077	.000123
419	3	1549-03	3.9	12	1.66	2.79	2.34	.0770	.0320	.0590	.0110	.0033	.0091	.300	.124	.244	.0077	.0026	.0067	.000338	.000106	.000218
420	4	1566-00	4.7	35	9.44	8.62	8.26	.0240	.0230	.0260	.0059	.0050	.0060	.121	.086	.105	.0029	.0027	.0037	.000257	.000112	.000248
421	2	1602-01	4.7	33	8.79	9.89	8.53	.0460	.0180	.0390	.0210	.0036	.0140	.281	.091	.177	.0060	.0014	.0046	.000199	.000080	.000165
422	2	1602-02	4.8	24	8.45	9.47	9.11	.1100	.0350	.0800	.1100	.0130	.0650	.385	.139	.328	.0121	.0038	.0080	.000684	.000166	.000447
423	2	1602-03	4.0	32	5.59	10.97	6.95	.0350	.0078	.0280	.0075	.0007	.0061	.125	.031	.112	.0034	.0007	.0033	.000123	.000070	.000132
424	4	1571-01	4.1	16	4.32	5.62	7.18	.0700	.0530	.0400	.0240	.0180	.0130	.402	.325	.296	.0149	.0037	.0058	.000801	.000201	.000260
425	4	1571-02	3.5	16	2.25	4.45	3.95	.0410	.0280	.0230	.0043	.0038	.0023	.236	.123	.087	.0043	.0017	.0014	.000140	.000052	.000065
426	4	1571-03	3.7	16	8.97	4.18	3.90	.0130	.0420	.0420	.0017	.0082	.0078	.086	.175	.314	.0016	.0021	.0046	.000060	.000060	.000198
427	4	1571-08	4.5	18	2.76	5.71	3.83	.2100	.0830	.1400	.1300	.0440	.0790	1.181	.365	.641	.0274	.0052	.0156	.001395	.000141	.000637
428	4	1571-11	4.4	18	6.84	7.84	8.04	.0200	.0150	.0170	.0031	.0019	.0026	.128	.065	.121	.0031	.0012	.0031	.000091	.000022	.000130
429	4	1571-16	4.7	16	7.48	10.72	8.65	.0250	.0180	.0240	.0051	.0040	.0057	.184	.109	.213	.0047	.0018	.0051	.000115	.000047	.000250
430	1	1583-03	4.4	21	13.22	17.01	14.99	.0750	.0280	.0550	.0920	.0150	.0590	.726	.215	.442	.0194	.0050	.0156	.001174	.000223	.000623
431	1	1583-04	4.7	21	5.07	8.75	5.28	.0470	.0180	.0390	.0130	.0032	.0087	.331	.092	.176	.0120	.0020	.0046	.000542	.000112	.000198
432	4	1571-10	4.6	24	19.32	16.75	16.48	.0720	.0770	.1000	.1100	.1100	.1900	.534	.418	.837	.0154	.007				

7.1 Introduction

Ce mémoire a été consacré aux investigations sur les mouvements forts en Iran. Le premier catalogue des mouvements forts a été établi au cours de ce travail, et plusieurs études "de base" sur ces données ont été effectuées. Le catalogue des données iraniennes des mouvements forts fournit une base de données très riche de cette région du monde qui possède une forte sismicité. Le réseau accélérométrique iranien, installé depuis 24 ans, fournit des informations sur les propriétés des séismes forts en Iran. Le réseau est toujours en cours de développement, surtout depuis le séisme de Manjil du 20 juin 1990. L'installation de stations sur différents types de sols a fourni la possibilité d'étudier les effets de site. Une classification des sites pour montrer leur réponse aux mouvements forts a été présentée. Dans ces études, l'énergie des mouvements forts et la durée ont été examinées. Les lois d'atténuations pour les mouvements forts ont été présentées pour les valeurs maximales et pour les valeurs spectrales.

Nous résumerons tout d'abord les principales conclusions de chaque thème, puis des suggestions générales pour continuer les études de "sismologie de l'ingénieur" en Iran seront exposées.

7.2 Catalogue des mouvements forts en Iran

Un catalogue des mouvements forts en Iran a été donc fourni. Ce catalogue donne les informations correspondant aux sources et aux sites des enregistrements accélérométriques. Les valeurs maximales de l'accélération, de la vitesse et du déplacement pour chaque enregistrement ont été présentées en compagnie des paramètres de la source pour l'événement correspondant à chaque enregistrement. Les données pour lesquelles on pouvait retrouver la source sismique par les bulletins téléseismiques (279 enregistrements en trois composantes) sont composés de 169 enregistrements analogues (SMA-1) et 108 enregistrements digitaux (SSA-2). La plupart des données iraniennes viennent de la région de Zagros, par contre il y a très peu d'enregistrements dans les régions comme Makran, Koppeh-Dagh et l'est de l'Iran (car ces régions sont très peu peuplées). La plupart de ces données correspondent à des séismes de magnitude 4 à 6, et à des distances comprises entre 0 et 80 kilomètres. Il existe également des enregistrements de séismes majeurs (comme le séisme de Tabas du 1978, et de Manjil du 1990) avec les magnitudes de plus de 7, qui ajoutent les données pour des distances de plus de 150km au catalogue présent. L'achèvement de ce catalogue s'est effectué en prenant en compte les 189 données digitales (en trois composantes) pour lesquels aucune information téléseismique ne pouvait être trouvée.

7.3 Moment sismique et la chute de contrainte

Les moments sismiques ont été calculés pour toutes les données, y compris les données pour lesquelles les rapports téléseismiques n'existent pas. Le niveau de l'amplitude maximale sur les spectres de Fourier de l'accélération (A_0) et les fréquences coin (f_c) ont été calculés. Les distances hypocentrales pour tous les enregistrements ont été estimées à partir des différences des arrivées des ondes P et S. Une échelle homogène de magnitude (M_w) a été choisie basée sur les résultats acquis pour les moments sismiques. Les magnitudes de moment (M_w) supérieures à 6.0 sont en accord avec les magnitudes d'ondes de surface (M_s), et les M_w inférieures à 6.0 sont proches des magnitudes d'ondes de volume (m_b). En utilisant ce critère, les magnitudes de moment ont été estimées à partir de leur M_s ou m_b (si leur magnitude était inférieure ou supérieure à 6.0), même pour les données pour lesquelles le calcul de M_w n'était pas possible. Cette homogénéisation était nécessaire pour les régressions qui sont effectuées pour la suite. Les chutes de contraintes ont été également étudiées, pour la première fois en Iran, en appliquant les résultats des mesures des fréquences coin et des amplitudes de spectres de Fourier des données. Les valeurs des chutes de contrainte pour les séismes iraniens, tombent bien dans le domaine des chutes de contrainte déjà présentées pour les séismes intra-plaque.

7.4 Études des effets de site

Les effets de sites dans les données iraniennes ont été étudiés en utilisant les résultats des investigations géotechniques. Des tests de profil de vitesse des ondes S et P, de mesures de bruit du fond et des profils géoélectriques ont été effectués en 26 sites, choisis en fonction de nombre d'enregistrements. Les tests de bruit du fond ont été réalisés également dans 24 autres sites. Les rapports H/V ont également été calculés pour tous les enregistrements (même pour ceux qui viennent des stations pour lesquelles les investigations géotechniques- géophysiques ont été faites). Les bandes de fréquences de l'amplification ont été utilisées pour distinguer les réponses variées des différents sols aux mouvements forts. Cette classification en 4 classes a été comparée aux résultats des profils des ondes S et P pour les 30 premiers mètres de profondeur (qui est en général la base des classifications des effets de sites dans les codes américains). Il y a un accord, dans 70% des cas, entre ces deux résultats: la classe 1 est le site le plus dur, avec les amplifications du rapport H/V ($R_{H/V}$) de moins de 3, ou plus de 3 dans les fréquences de plus de 15 Hz avec les Vs dans premier 30m de plus de 700m/s, la classe 2 concerne aux sites avec les amplifications du $R_{H/V}$ plus de 3 pour les fréquences comprises entre 5 au 15Hz avec les Vs

pour le premier 30m entre 500m/sec et 700 m/sec, la classe 3 est composée des sites avec des amplification du R H/V plus de 3 pour les fréquences entre 2 et 5 Hz avec les Vs dans premier 30m entre 300m/sec et 500 m/sec, et la classe 4 est consisté des sites avec les amplification plus du R H/V de plus de 3 dans les fréquence de moins de 2Hz avec les Vs 1er 30m de moins de 300m/sec (le site le plus mou). Cette classification a été la première dans les catégorisation des effets de sites du point de vue de leur réponse aux mouvements forts, dans laquelle les rapports H/V sont utilisées.

Les rapports H/V pour le bruit de fond (effectués pour 50 sites) ne sont que rarement en accord avec les rapports H/V des enregistrements de mouvement forts pour les mêmes sites. Cela peut être dû à la situation météorologique et topographique du plateau iranien. Les seuls exemples pour lesquels les rapports H/V des bruits du fonds montrent les amplifications dans les même bandes de fréquence que les rapports H/V de mouvements forts, sont les sites de classe 4, qui sont soit en bord de mer (comme les site de Lahijan et Rudsar), soit sur les sols mous d'épaisseur importante (Bajestan et Shiraz).

Les non-linéarités éventuellement ont été analysés en calculant de différences entre les observations sur les sites 3 et 4. Les valeurs observées pour les basses fréquence sont significatives pour ces effets, qui doivent être l'objet des prochaines études en Iran. On propose donc l'observation précise des mouvement forts dans les régions très sismiques (comme Zagros) sur les sols de types 3 et 4 (les sols mous) en utilisant les réseaux locaux. Les limites qui viennent des données doivent être respectés pour l'utilisation de ces lois: il faut appliquer les lois de cette thèse, pour une estimation optimum, dans les magnitude de 3 à 7 dans Zagros et 3 à 7.4 dans le reste de pays, et les distance de 10 à 50km dans Zagros et 20 a 200 pour le reste de pays. Les études déterministes spécifiques pour le champs proche (distance inférieure à 10km) doivent être utilisées.

7.5 Énergie et durée des mouvements forts en Iran

La durée est un paramètre d'énergie (l'énergie de l'accélération) proporsionnel à l'intensité d'Arias, et l'accélération moyenne quadratique (a_{rms}) ont été étudiées. Les durées sont différentes en Zagros et dans le reste du reste du pays. Ce problème vient probablement de la sismicité eblement des autre facteurs. κ a été étudié séparément pour les données iraniennes, et les résultats ont été plus ou moins différents pour la région de Zagros et pour le reste du pays, mais cette différence n'est pas très claire. Les atténuation de Arms et d'énergie de l'accélération (e_a) ont été également présentés dans ce chapitre. Les régressions sur les valeurs de la durée

donnent un écart-type moins fort quand on utilise les données obtenues pour des distances hypocentrales inférieur à 50km (où la plupart des données ont été enregistrées).

Les conditions des sites se sont avérés sans influence significative sur la durée.

Les estimations des modèles empiriques d'atténuation de A_{rms} et e_a pour les ondes de volumes et les ondes de surface sont différents surtout dans les premiers 20 km, où justement les valeurs prédites avec le coefficient des ondes de volume sont plus élevés.

7.6 Atténuation des mouvements forts en Iran

Les lois d'atténuation en Iran ont été présentées non seulement pour les valeurs maximales de l'accélération, de la vitesse et du déplacement, mais aussi pour les valeurs spectrales des l'accélération. Ces lois sont fournies séparément pour les régions de Alborz-Iran Central, Zagros, et pour l'ensemble des données iraniennes. Les régressions ont été faites en utilisant les paramètres explicatives comme la distance hypocentrale, la magnitude M_w et les coefficients de sites (pour l'ensemble des 4 classes présentées).

A partir des observations sur les sites 3 et 4, les valeurs observées pour les basses fréquence sont significatifs pour les effets inattendus. Ces effets doivent être étudiés dans les prochaines investigations en Iran. Une étude sur les basses fréquences basée sur les observations des mouvements forts dans les régions très sismique (comme Zagros) sur les sol de types 3 et 4 (les sols mous) en utilisant les réseaux locaux serait intéressante à mener.

Les limites qui viennent des données doivent être respectées pour l'utilisation de ces lois: il conviendra de n'appliquer les lois de cette thèse, que pour les distances comprises entre 10 et 50km dans le Zagroso (et magnitude comprise entre 4 et 6.5), et des distances comprises entre 20 rt 200km dans l'Iran-Cenral (magnitude comprise entre 4 et 7.4). Les études déterministes spécifiques sont recommandés pour le champ-proche.

7.7 Propositions pour la continuation de ces recherches

Les études sur les mouvements forts en Iran peuvent être développées dans plusieurs directions différentes. Mais au préalable, il est nécessaire de consolider et d'étendre le réseau accélérométrique en Iran, de façon à fournir une base des données plus riche. Les propositions pour la continuations des études en « Sismologie de l'ingénieur » en Iran sont classifiées comme suit:

1. Le réseau sismographique du pays doit absolument être développé de façon à ce que les épicentres des événements sismiques en Iran soient localisés précisément. Ce problème est très important pour poursuivre les études des atténuations et de l'aléa sismique en Iran, parce que tant que les localisations ne sont pas précises, la détermination et la définition des distances pour les lois d'atténuation ne pourront pas être améliorées.

2. Des réseaux accélérométriques locaux peuvent être installés dans les régions très actives (comme le Zagros) pour étudier les effets de sites ou de source avec les méthodes différentes. Dans ces réseaux locaux, les comparaisons des résultats des méthodes numériques et expérimentales seront possibles. Les régions côtières de la mer Caspienne et du golfe Persique sont les plaines où l'on trouve des sols mous avec une nappe phréatique assez superficielle: nous les proposons donc en priorité pour ces réseaux locaux. Ils peuvent aussi faire l'objet d'installations spécifiques dans les plaines de Gilan et de Mazandaran au nord, et Khuzestan au sud, et les plaines du sud de Téhéran, de l'est de Shiraz, au nord et à l'ouest de Bandarabbas, au sud de Tabriz, ... etc.).

3. L'installation d'un récepteur horaire sur toutes les stations pour les obtenir en temps absolu peut fournir les données nécessaires pour l'analyse de la rupture. En utilisant ce paramètre spectral, l'estimation préliminaire des zones macrosismiques sera possible avec un réseau dense.

4. Le filtrage des enregistrements accélérométriques en Iran doit se faire avec les estimations des spectres de signaux et du bruit. Les données disponibles, auparavant en Iran, quoique nombreuses, ont pu conduire à des mauvaises interprétations, voire à des erreurs en raison de l'inadéquation des traitements réalisés.

5. La distribution des données iraniennes sur le réseau « Internet » peut fournir l'occasion d'échange des données avec les scientifiques internationaux. Aujourd'hui, la communication entre les chercheurs des pays différents, qui ont des approches variées, est essentielle.

6. Les meilleures données peuvent être utilisées pour des estimations plus précises de l'énergie, de la durée, du moment sismique, du facteur de qualité (Q) et du facteur d'absorption (κ). Ces types de calculs peuvent aider à une meilleure compréhension des effets de source, de propagation et de site. Ces études peuvent aussi conduire à la possibilité d'un zonage en Iran de point de vue de l'atténuation des mouvements forts.

7. Le spectre d'aléa sismique uniforme devraient être étudié en Iran sur la base d'une étude précise de la sismicité de l'Iran.

8. La sélection de nouveaux sites des stations accélérométriques en Iran doit être effectuée en considérant la situation géologique et sismologique des différentes régions de pays. En particulier des paires de stations proches (une sur l'alluvions et l'autre sur le rocher) peuvent fournir les

données pour les études expérimentales des effets de site.

9. Les études sur le champ-proche sont essentielles pour l'Iran. A cause de l'approvisionnement en eau, presque partout en Iran, les villes et les villages sont édifiées au pied des montagnes ou collines, où la nappe phréatique est très superficielle. Ces endroits correspondent en fait à la plupart des failles quaternaires. Donc beaucoup de zones urbaines se trouvent à proximité immédiate de sources importantes.

10. Les données accélérométriques des pays voisins (surtout Turquie, Arménie, Azarbayjan) peuvent être le sujet d'études comparatives. Les situations géologiques en Iran et en Turquie sont similaires. Ce type d'études peut aider les investigations de l'aléa sismique dans la région méditerranéenne.

11. Enfin, l'étude de l'atténuation des intensités macrosismiques serait souhaitable aussi pour l'Iran. On propose la calibration de l'échelle européenne de EMS98 pour une étude plus précise sur les intensités en Iran. Les destructions historiques pourraient alors indiquer l'aléa sismique dans un pays comme Iran, qui a un grand héritage culturel, historique et archéologique.

Chapitre 8

Bibliographie Générale

- Abrahamson N.A. and K.M. Shedlock (1997), Overview (special issue of SRL on the Attenuation of Strong motion), *Seism. Research Let.*, Vol. 68, No.1, pp.9-24.
- Abrahamson N.A. and W.J. Silva (1997), Empirical Response Spectral Attenuation Relationships for Shallow Crustal Earthquake, *Seism. Research Let.*, Vol. 68, No.1, pp.86-93.
- Aki, K. (1967), Scaling law of Seismic spectrum, *J. Geoph. Res.*, Vol.72, pp.1217-1231.
- Ambraseys N.N. (1988), Engineering Seismology, Earthquake Eng. and Structural Dyn., Vol.17, No.1, pp.1-105.
- Ambraseys N.N. (1995), The Prediction of Earthquake Peak Ground Acceleration in Europe, *Earthquake Eng. Struct. Dyn.* Vol.24, pp.467-490.
- Ambraseys N.N., and M. W. Free (1997), Surface Wave Magnitude Calibration for European Region Earthquakes, *Journal of Earthquake Eng.* Vol.1, No.1, pp.1-22.
- Ambraseys N.N. and C.P. Melville (1982), A History of Persian Earthquakes, Cambridge University Press.
- Ambraseys N.N., and K. A. Simpson (1996), Prediction of Vertical Response Spectra in Europe, *Earthquake Eng. Struct. Dyn.* Vol.25, pp.401-412.
- Ambraseys N.N., and M. Srbulov (1998), A Note on the Point Source Approximation in Ground Motion Attenuation Relations, *Journal of Earthquake Eng.* Vol.2, No.1, pp.1-24.
- Anderson J.G. and S.E. Hough (1984), A Model for the Shape of the Fourier Amplitude Spectrum of Acceleration at High Frequencies, *Bul. of the Seis. Soc. of America*, Vol.74, No.5, pp.1969-1993.

- Arias A. (1970), A Measure of Earthquake Intensity, in *Seismic Design of Nuclear Power Plants*, R.J. Hansen Editor, M.I.T. press.
- Bard, P.-Y., Duval A.-M., Lebrun B., Lachet C., Riepl J., and Hatzfeld D. (1997), Reliability of H/V Technique for Site Effects Measurement: An Experimental Assessment, SDEE'97, Proc. Of the Eight International Conf. on Soil dynamics and Earthquake Eng. , Istanbul, in press, 8p.
- Bard, P.-Y, M. Zaré and M.Ghafory-Ashtiany (1998), The Iranian Accelerometric Data Bank, A Revision and Data Correction, *Journal of Seismology and Earthquake Engineering*, Vol.1, No.1, pp1-22.
- Berberian M. (1976), Contribution to the Seismotectonics of Iran, (PartII), *Geol. Sur. Iran*, Rep. 39, 518p.
- Berberian M. (1977), Contribution to the Seismotectonics of Iran, (PartIII), *Geol. Min., Sur. Iran*, Rep. 40, 300p.
- Berberian M. (1981), Active Faulting and Tectonics of Iran, , In: H.K. Gupta and F.M. Delany (Editors), *Zagros-Hindu Kush-Himalaya Geodynamic Evolution*, *Amr. Geophy. Union*, *Geodyn. Ser.*, Vol.3, pp.33-69.
- Berberian M. (1982), Aftershock tectonic of the Tabas-e-Golshan (Iran) Earthquake Sequence: A Thick and Thin skinned Tectonic' Case, *Geoph. J. R. astr. Soc.*, Vol.68, pp.499-530.
- Berberian M.et al. (1984), Field and Teleseismic Observations of the 1981 Golbaf-Sirch Earthquakes in SE Iran, *Geoph. J. R. ast. soc.* Vol.77, pp. 809-838.
- Berberian M. (1995), Master Blind Thrust Faults hidden under the Zagros Folds: Active Basement Tectonics and Surface Morphotectonics, *Tectonophysics*, Vol.241, pp. 193-224.

- Berberian M., M. Qorashi, J.A. Jakson, K. Priestley and T. Wallace (1992), The Rudbar-Tarom Earthquake of 20 June 1990 in NW Persia: Preliminary field and Seismological Observations, and its Tectonic Significance, *Bul. of Seismological Soc. of America*, Vol.82, No.4, pp.1726-1755.
- Boore D. M., W.B. Joyner and T.E. Fumal (1993), Estimation of Response Spectra and Peak Accelerations from Western North American Earthquakes: An Interim Report, U. S. Geol. Survey, Open-file report: 93-509. 72.p.
- Boore D. M., W.B. Joyner and T.E. Fumal (1994), Estimation of Response Spectra and Peak Accelerations from Western North American Earthquakes: An Interim Report, U. S. Geol. Survey, Open-file report: 94-127. 40.p.
- Boore D. M., W.B. Joyner and T.E. Fumal (1997), Equations for Estimating Horizontal Response Spectra and Peak Acceleration from Western North American Earthquakes: A Summary of Recent Work, *Seism. Research Let.*, Vol. 68, No.1, pp.128-153.
- Brillinger D.R. and H. K. Priestler (1984), An Exploratory Analysis of the Joyner-Boore Attenuation Data, *Bul. of Seismological Soc. of America*, Vol.74, No.4, pp.1441-1450.
- Brillinger D.R. and H. K. Priestler (1985), Further Analysis of the Joyner-Boore Attenuation Data, *Bul. of Seismological Soc. of America*, Vol.75, No.4, pp.611-614.
- Brune, J.N. (1970), Tectonic stresses and the spectra of seismic shear waves, *J. Geoph. Res.*, Vol.75, pp.4997-5009.
- Brune, J.N. (1971), Corrections, *J. Geoph. Res.*, Vol.76, p.5002.

- BSSC (1994), NEHRP Recommended Provisions for Seismic Regulations for New Buildings, Part 1- Provisions, FEMA; Federal Emergency Management Agency, 222A, 290p.
- Building and Housing Research Center (1992), Accelerograms of the Manjil Iran Earthquake of 20 June 1990, Vol.2, Pub.No.143.
- Building and Housing Research Center (1993), A Collection of the Accelerogram Network of the Islamic Republic of Iran, Pub. No.179, 173p.
- Bullen K. E. and B. A. Bolt (1985), An Introduction to the Theory of Seismology, Cambridge Univ. Press, 4th Edi., 499 p.
- Caillot V. (1992), Quantification Statistique et Etude Expérimentale des Mouvements Sismiques, Application à l'évaluation du Risque, Ph.D thesis, Observatoire de Grenoble, Université Joseph-Fourier, (published by 'études et recherches des laboratoire des points et chaussées, série géotechnique GT51, January 1993). 192p.
- Campbell K.W. (1981), Near-Source Attenuation of Peak Horizontal Attenuation, *Bul. of Seismological Soc. of America*, Vol.71, No.6, pp.2039-2070.
- Duval, A.M. (1994), Détermination de la réponse d'un site aux séisme à l'aide de bruit de fond: Evaluation expérimental, Thèse de Doctorat, Université Pierre et Marie Curie, Paris.
- Duward J.A., D.M. Boore and W.B. Joyner (1996), The Amplitude Dependence of High Frequency Spectral Decay: Constraint on Soil Non-linearity, *Proc. Int. Workshop on Site Response*, Yokusoka Japan, pp.82,103.
- Eslami A.A., and P. Mozaffari (1992), Qualitative and Quantitative Analysis of Rudbar Earthquake (Northern Part of Iran), in the Selected papers of the International Conf. on

- Continental Earthquakes, IASPEI Publication Series for the IDNDR, Vol.3, pp. 114-121.
- Eshghi S. et al. (1994), Ebrahimabad Earthquake of 20 June 1994, and a Review on the Southern Zagros Earthquakes of Charak and Dadenjan of 1992 and Mouk of 1994, IIEES Newsletter (Pajouheshnameh), Vol.3, No.3, special issue. (in Persian).
- Esteva L. (1970), Seismic Risk and Seismic Design Criteria for Nuclear Power Plants, The MIT Press (edited by J. Hansen), Cambridge, Massachusetts, pp. 142-182.
- Frankel A. (1991), High-Frequency Spectral Falloff of Earthquakes, Fractal dimension of Complex Rupture, b Values, and the Scaling of Strength on Faults, J. Geoph. Res., Vol.96, N.B4, pp.6291-6302.
- Fukushima Y. and T. Tanaka (1990), A New Attenuation Relation for Peak Horizontal Acceleration of Strong Earthquake Ground Motion in Japan, Bul. of Seismological Soc. of America, Vol.80, No.4, pp.757-783.
- Fukushima Y., J.-C. Gariel and R. Tanaka (1995), Site-Dependent Attenuation Relations of Seismic Motion Parameters at Depth Using Borehole Data, Bul. of Seismological Soc. of America, Vol.85, No.6, pp.1790-1804.
- Fukushima Y., T. Tanaka and S. Kataoka (1988), A New Attenuation Relationship for Peak Ground Accelerations derived from Strong Motion Accelerograms, Proc. 9th World Conf. on Earthquake Eng., Vol. pp.343-348.
- Gariel J.-C. and M. Campillo (1989), The Influence of the Source on the High-Frequency Behavior of the Near-Field Acceleration Spectrum: A Numerical Study, Geoph. Res. Lett., Vol.16, No.4, pp.279-282.

- Hanks, T.C. (1979), b Value and ω^γ seismic Source models: implications for Tectonic Stress Variations along Active Crustal Fault Zones, J. Geoph. Res., Vol.84, pp.2235-2242.
- Hanks T.C. (1982), f_{max} , Bull. Seismol Soc. of America, Vol.72, pp.1867-1880.
- Hanks T.C. and H. Kanamori (1979), A Moment Magnitude Scale, J. of Geoph. Res., Vol.84, No.B5, pp.2348-2350.
- Haskell N.A. (1964), Total Energy and Energy Spectral Density of Elastic Wave Radiation from Propagating Faults, Bull. Seismol Soc. of America, Vol.54, pp.1811-1841.
- Heydari M. and M. Zaré (1995), Seismotectonics of Recent Earthquakes in Western Fars Area; Southern Zagros Iran, Proc. 2nd Int Conf. on Seismology and Earthquake Engineering (SEE-2), Tehran, Vol.2, pp. 1279-1300.
- Husid R., H. Median and J. Rios (1969), Analysis de terremotos Norteamericanos y Japonenses, Revista del IDIEM 8, Chile.
- Jafari M.K., M. Kamalian and M. Chamanzad (1995), Microzonation of the Tehran Region, Proc. 2nd Int. Conf. On Seismology and Earthquake Engineering (SEE-2), Tehran, Vol.2, pp.1301-1311.
- Jafari M.K., M. Kamalian and M. Chamanzad (1996), Microzonation Study in the Tehran Region, Proc. 11th World Conf. on Earthquake Engineering (WCEE), Accopolco, paper no. 895.
- Jackson J. and D.P. McKenzie (1984), Active Tectonics of the Alpine Himalayan Belt between western Turkey and Pakistan, Geoph. J. R. Astron. Soc., Vol.77, pp. 185-264.

Jackson J. and D.P. McKenzie (1988), The Relationship between the Plate Motions and Seismic Moment Tensors, and the Rates of the Active Deformation in the Mediterranean and Middle East, *Geoph. J. R. Astron. Soc.* Vol.93, pp.45-73.

Japan Working Group for TC-4 Committee (1992), Seismic Zoning on Geotechnical Hazards, Draft, 114P.

Jeong, G.D. and W.D. Iwan (1988), The Effect of Earthquake Duration on the Damage of Structures, *Earthq. Eng. Struct. Dyn.*, Vol.16, pp.1201-1211.

Joyner W.B. and D. M. Boore (1981), Peak Horizontal Acceleration and Velocity from Strong Motion Records from the 1979 Imperial Valley, California, Earthquake, *Bul. of Seismological Soc. of America*, Vol.71, No.6, pp.2011-2038.

Joyner W.B. and D. M. Boore (1993), Methods for Regression Analysis of Strong Motion Data, *Bul. of Seismological Soc. of America*, Vol.83, No.2, pp.469-487.

Kadinsky-Cade K. and M. Barazangi (1982), Seismotectonics of Southern Iran, *Tectonics*, Vol.1, No.5, pp.389-412.

Kanamori, H. (1977), The Energy Release in Great Earthquakes, *J. Geoph. Res.*, Vol.82, pp.2981-2987.

Kanamori H., and D.L. Anderson (1975), Theoretical Basis of some Empirical Relations in Seismology, *Bull. Seismol Soc. of America*, Vol.65, pp.1073-1095.

Koliopoulos B.N, B.N. Margaritis and N.S. Klimis (1998), Duration and Energy Characteristics of Greek Strong motion Records, *Journal of Earthquake Eng.*, Vol.2, No.3, pp.1-27.

Konno K., and T. Ohmachi (1998), Ground Motion Characteristics Estimated from Spectral Ratio between Horizontal and Vertical Components of Microtremors, *Bull. of the Seismological society of America*, Vol. 88, No.1, pp. 228-241.

Lachet C., Hatzfeld D., Bard P.-Y., Thodulidis N., Papaioannou C., and A. Savvaidis (1996), Site Effects and Microzonation in the City of Thessaloniki (Greece) Comparison of Different Approaches, *Bull. of the Seismological society of America*, Vol. 86, No.6, pp. 1692-1703.

Lacave-Lachet C., P.Y. Bard, J.C. Gariel, and K. Irikura (1998), Straightforward Methods to Detect non-linear response of the Soil. Application to the Recordings of the Kobe Earthquake (Japan 1995), submitted to the *Journal of Seismology*, 25p.

McCann Jr. M.W. and H. Shah (1979), Determining Strong Motion Duration of Earthquakes, *Bull. Seismol. Soc. of America*, Vol.69, No.4, pp.1253-1265.

Moinfar A.A. and H. Adibnazari (1982), The Tabas Earthquake of September 16, 1978, Building and Housing Research Center, Technical Rep. No.47.

Moinfar A.A. M. Eetemadi (1982), Accelerograms of the Golbaf-Sirch 1982 Earthquakes, Building and Housing Research Center, Internal Report., (in Persian).

Moinfar A.A. and Shoja-Taheri J. (1988), Fathabad-Ghir, Iran Earthquake Study of the Strong Motions Records, *Proc. 9th World Conf. on Earthquake Engineering*, Tokyo-Kyoto, Vol.VIII, pp.149-154.

Moinfar A.A. and A. Naderzadeh (1990), An Immediate and Preliminary Report on the Manjil Iran Earthquake of 20 June 1990, Building and Housing Research Center, Rep. No.119, 68p.

- Nabavi M.H. (1975), An introduction to the Geology of Iran, Geol. Sur. Iran.
- Ni J. and M. Barazangi (1986), Seismotectonics of the Zagros Continental Collision Zone and a Comparison with the Himalayas, *J. of Geoph. Res.*, Vol.91, No.B8, pp.8205-8218.
- Niazi M. (1986), Accelerograms of the 1978 Tabas, Iran, Earthquake, *Earthquake Spectra* . Vol.2, pp.635-651.
- Niazi M. and Y. Bozorgnia (1992), The 1990 Manjil, Iran Earthquake: Geology and Seismology Overview, PGA Attenuation, and Observed Damage, *Bulletin of the Seismological Society of America*, Vol.82, No.4, pp.774-799.
- Page R. A., D.M. Boore and J.H. Deitrich (1975), estimation of Bedrock motion at the Ground surface, Profess. Paper 941-A.
- Papageorgiou A.S. and K. Aki (1983), A specific Barrier model for the Quantitative Description of Inhomogeneous Faulting and the Prediction of the Strong Ground Motion. I. Description of the Model, *Bul. of the Seis. Soc. of America*, Vol.73, No.3, pp.693-722.
- Riepl, J., Bard P.-Y., Hatzfeld D., Papaioannou C. and S. Nechtschein (1998), Detailed Evaluation of Site Response Estimation Methods Across and Along the Sedimentary Valley of Volvi (EURO-SEISTEST), *Bull. of the Seismological society of America*, Vol. 88, No.2, pp. 488-502.
- Saikia C.K. (1994), Modeling of Strong Ground Motions from the 16 September 1978 Tabas, Iran, Earthquake, *Bulletin of the Seismological Society of America*, Vol.84, No.1, pp.31-46.
- Shoja-Taheri J. (1984), Accelerograms of the 1978 Tabas (Iran) Earthquake: The Generalized records and Correlations between the Strong Motion Parameters in Different Frequency

- Bands, Presented at Regional Assembly of IASPEI, Heyderabad, India.
- Shoja-Taheri J. and J. Anderson (1988), The 1978 Tabas, Iran, Earthquake: An Interpretation of the Strong Motion Records, *Bulletin of the Seismological Society of America*, Vol. 78, No.1, pp.142-171.
- Theodulidis, N. and P.-Y. Bard (1995), (H/V) Spectral ratio and geological conditions: an analysis of strong motion data from Greece and Taiwan (SMART-1), *Soil Dynamics and Earthquake Engineering*, 14: pp.177-197.
- Trifunac M.D. and A.G. Brady (1975), A Study on the Duration of the Strong Earthquake Ground Motions, *Bull. Seismol. Soc. of America*, Vol.65, No.3, pp.581-626.
- Uang C.M., and V.V. Bertero (1990), Evaluation of Seismic Energy in Structures, *Earthq. Eng. Struct. Dyn.*, Vol.19, pp.77-90.
- Udwadia F.E. and M.D.Trifunac (1974), Characterization of the Response Spectra through the Statistics of Oscillator Response, *Bull. Seismol Soc. of America*, Vol.64, No.1, pp.205-219.
- Vanmarcke E.H. and S.-S. P. Lai (1980), Strong Motion duration and RMS Amplitude of Earthquake Records, *Bull. Seismol Soc. of America*, Vol.70, No.4, pp.1293-1307.
- Zaré M. (1991), The Seismotectonic and Neotectonic Analysis of the Reconstruction Operation of the Sefid-Rud Dam, with the Special Reference to the Earthquake of 20th June 1990, NW Iran, *Proc. of the 5th Int. Conf. on Soil Dynamics and Earthquake Engineering*, vol.2, Karlsruhe, Computational Mechanics Pub. Southampton.
- Zaré M. (1993), Macrozonation of the Landslides for the Manjil Iran 1990 Earthquake, *Proc. 3rd Int. Conf. on Case-Histories in Geotechnical Eng.* Vol.1, Univ. of Missouri-Rola, St.

Louis.

Zaré M. (1994), The Study of Site Effects on the Strong Ground Motions during Earthquakes, a Case-Study on the Manjil 1990 Earthquake, M.Sc. Thesis, Engineering Geology Dept. Tarbiat-Modarres University, Tehran, 214p., (in Persian).

Zaré M. and A.A. Moïnfar (1994), Comment on the 'Rudbar-Tarom Earthquake of 20 June 1990, in NW Persia : a Preliminary Field and Seismological Observations and its Tectonic Significance « by; Berberian et al 1992 », Bulletin of the Seismological Society of America, Vol.84, No.2, pp.484-485.

Zaré M. (1995), Site Dependent Attenuation of Strong Motions for Iran, Seismic Zonation, 5th Int. Con. Nice, Ouest Pub. Paris. Vol.2, pp.1227-1236.

Zaré M. (1996), Deux Exemple de Mouvements de Forts Séismes en Champ proche en Iran, 4ém Colloque National en Génie Parasismique, AFPS, Paris, Proc. Vol.1, pp.112-119.

Zaré M., P-Y. Bard, M.Ghafory-Ashtiany (1999a), Site Characterizations for the Iranian Strong Motion network, Journal of Soil Dynamics and Earthquake Engineering, Vol.18, no.2, pp.101-123.

Zaré M., P-Y. Bard, M.Ghafory-Ashtiany (1999b), Moment Magnitude for the Strong Motion Accelerograms in Iran, in preparation, 22 pages.

Zaré M., P-Y. Bard, M.Ghafory-Ashtiany (1999c), Duration and Energy Content of Strong Motions in Iran, submitted to the Journal of Earthquake Engineering, 42 pages.

Zaré M., P-Y. Bard, M.Ghafory-Ashtiany (1999d), Strong Motion Attenuation in Iran, submitted to the Bulletin of the Seismological Society of America.

Chapitre 9

Annexes

Annexe-1: Valeurs de fréquence (Hz) pour lesquelles les regressions ont été effectuées sur les ordonnées spectrales (d'après Fukushima: programme FORTRAN de la régression pour la loi d'atténuation)

0.100	0.111	0.125	0.143	0.167	0.182	0.200
0.222	0.250	0.263	0.278	0.294	0.300	0.312
0.333	0.357	0.385	0.400	0.417	0.455	0.500
0.556	0.600	0.625	0.667	0.700	0.714	0.769
0.800	0.833	0.900	0.909	1.000	1.100	1.111
1.176	1.200	1.250	1.300	1.333	1.400	1.429
1.471	1.500	1.515	1.562	1.600	1.613	1.667
1.700	1.724	1.786	1.800	1.852	1.900	1.923
2.000	2.083	2.100	2.174	2.200	2.273	2.300
2.381	2.400	2.500	2.600	2.632	2.700	2.778
2.800	2.900	2.941	3.000	3.125	3.155	3.300
3.333	3.448	3.571	3.600	3.800	3.850	4.000
4.167	4.200	4.400	4.550	4.600	4.800	5.000
5.250	5.263	5.500	5.556	5.750	5.882	6.000
6.250	6.500	6.667	6.750	7.000	7.143	7.250
7.500	7.692	7.750	8.000	8.333	8.500	9.000
9.091	9.500	10.000	10.500	11.000	11.111	11.500
11.765	12.00	12.500	13.00	13.333	13.500	14.000
14.286	14.500	15.000	15.385	16.000	16.667	17.00
18.000	18.868	20.000	22.000	25.000	28.000	29.412
31.000	33.333	34.000	40.000	45.000	50.000	

Annexe-2: Nombre des points utilisés, valeurs de Sigma, a, b, c1, c2, c3, c4 pour 146 fréquences indiquées dans l'Annexe-1, pour l'ensemble des données iraniennes (composante horizontale), pour d=1.0 .

Points	6.009E+00	8.009E+00	8.009E+00	8.009E+00	1.380E+02	1.380E+02	1.420E+02	3.000E+02
3.720E+02	4.440E+02	4.480E+02	5.200E+02	5.300E+02	5.360E+02	5.380E+02	5.580E+02	
5.580E+02	5.900E+02	5.940E+02	6.320E+02	6.400E+02	6.540E+02	6.540E+02	6.540E+02	
6.560E+02	6.600E+02	6.600E+02	6.660E+02	6.660E+02	6.660E+02	6.760E+02	6.760E+02	
6.760E+02	7.220E+02	7.220E+02	7.220E+02	7.220E+02	7.240E+02	7.240E+02	7.240E+02	
7.240E+02	7.240E+02	7.240E+02	7.240E+02	7.240E+02	7.240E+02	7.500E+02	7.500E+02	
7.500E+02	7.500E+02	7.500E+02	7.500E+02	7.500E+02	7.500E+02	7.500E+02	7.500E+02	
7.480E+02	8.120E+02	8.120E+02	8.120E+02	8.120E+02	8.120E+02	8.120E+02	8.120E+02	
8.120E+02	8.120E+02	8.200E+02	8.200E+02	8.200E+02	8.200E+02	8.200E+02	8.200E+02	
8.200E+02	8.220E+02	8.900E+02	8.900E+02	8.900E+02	8.900E+02	8.900E+02	8.900E+02	
8.900E+02	8.900E+02	8.900E+02	8.860E+02	9.140E+02	9.140E+02	9.140E+02	9.140E+02	
9.140E+02	9.140E+02	9.100E+02	9.200E+02	9.200E+02	9.200E+02	9.200E+02	9.200E+02	
9.200E+02	9.140E+02	9.140E+02	9.140E+02	9.140E+02	9.140E+02	9.080E+02	9.080E+02	
9.080E+02	9.080E+02	9.080E+02	9.080E+02	9.000E+02	9.040E+02	9.040E+02	8.960E+02	
8.960E+02	8.960E+02	8.740E+02	8.740E+02	8.620E+02	8.620E+02	8.620E+02	8.620E+02	
8.580E+02	8.580E+02	8.580E+02	8.580E+02	8.580E+02	8.580E+02	8.580E+02	8.580E+02	
8.160E+02	8.160E+02	8.160E+02	8.020E+02	8.020E+02	7.920E+02	7.900E+02	7.440E+02	
7.420E+02	7.180E+02	7.060E+02	7.060E+02	6.600E+02	6.580E+02	6.580E+02	8.801E+01	
8.601E+01	9.360E-03							
σ	4.577E+00	6.746E+00	6.802E+00	6.872E+00	3.475E-01	3.479E-01	3.507E-01	3.095E-01
3.432E-01	3.309E-01	3.315E-01	3.411E-01	3.453E-01	3.411E-01	3.304E-01	3.306E-01	
3.309E-01	3.477E-01	3.473E-01	3.616E-01	3.619E-01	3.770E-01	3.822E-01	3.839E-01	
3.853E-01	3.876E-01	3.875E-01	3.932E-01	3.927E-01	3.943E-01	3.941E-01	3.937E-01	
3.907E-01	4.007E-01	4.013E-01	4.034E-01	4.038E-01	4.057E-01	4.070E-01	4.071E-01	
4.053E-01	4.042E-01	4.027E-01	4.024E-01	4.023E-01	4.091E-01	4.096E-01	4.101E-01	
4.131E-01	4.141E-01	4.146E-01	4.145E-01	4.142E-01	4.124E-01	4.113E-01	4.111E-01	
4.099E-01	4.203E-01	4.199E-01	4.190E-01	4.189E-01	4.192E-01	4.191E-01	4.193E-01	
4.195E-01	4.198E-01	4.196E-01	4.192E-01	4.184E-01	4.165E-01	4.161E-01	4.143E-01	
4.140E-01	4.144E-01	4.201E-01	4.202E-01	4.190E-01	4.190E-01	4.175E-01	4.152E-01	
4.148E-01	4.164E-01	4.165E-01	4.172E-01	4.139E-01	4.133E-01	4.093E-01	4.067E-01	
4.060E-01	4.015E-01	3.963E-01	3.915E-01	3.914E-01	3.876E-01	3.864E-01	3.830E-01	
3.814E-01	3.801E-01	3.792E-01	3.789E-01	3.791E-01	3.790E-01	3.748E-01	3.736E-01	
3.726E-01	3.691E-01	3.675E-01	3.671E-01	3.622E-01	3.593E-01	3.570E-01	3.564E-01	
3.563E-01	3.560E-01	3.528E-01	3.566E-01	3.584E-01	3.587E-01	3.593E-01	3.590E-01	
3.578E-01	3.564E-01	3.552E-01	3.545E-01	3.542E-01	3.555E-01	3.566E-01	3.577E-01	
3.601E-01	3.609E-01	3.616E-01	3.577E-01	3.584E-01	3.569E-01	3.549E-01	3.533E-01	
3.565E-01	3.514E-01	3.490E-01	3.461E-01	3.444E-01	3.373E-01	3.355E-01	3.734E-01	
3.626E-01	1.715E-01							
a	1.541E+00	8.031E-01	8.441E-01	8.891E-01	8.447E-01	8.556E-01	8.787E-01	7.996E-01
7.207E-01	7.209E-01	7.163E-01	7.225E-01	7.496E-01	7.531E-01	7.555E-01	7.563E-01	
7.573E-01	8.321E-01	8.361E-01	8.337E-01	8.279E-01	7.960E-01	7.921E-01	7.917E-01	
7.981E-01	8.023E-01	8.033E-01	8.186E-01	8.178E-01	8.175E-01	8.051E-01	8.042E-01	
7.975E-01	7.999E-01	7.997E-01	7.990E-01	7.979E-01	7.933E-01	7.881E-01	7.842E-01	
7.759E-01	7.723E-01	7.659E-01	7.599E-01	7.565E-01	7.520E-01	7.487E-01	7.478E-01	
7.458E-01	7.450E-01	7.436E-01	7.351E-01	7.328E-01	7.245E-01	7.176E-01	7.147E-01	
7.063E-01	6.714E-01	6.700E-01	6.650E-01	6.623E-01	6.554E-01	6.538E-01	6.476E-01	
6.461E-01	6.400E-01	6.294E-01	6.264E-01	6.220E-01	6.176E-01	6.163E-01	6.102E-01	
6.068E-01	6.025E-01	5.805E-01	5.799E-01	5.761E-01	5.749E-01	5.690E-01	5.627E-01	
5.611E-01	5.533E-01	5.510E-01	5.432E-01	5.291E-01	5.266E-01	5.134E-01	5.064E-01	
5.042E-01	4.973E-01	4.899E-01	4.749E-01	4.745E-01	4.671E-01	4.652E-01	4.586E-01	
4.549E-01	4.519E-01	4.451E-01	4.383E-01	4.338E-01	4.317E-01	4.309E-01	4.284E-01	
4.258E-01	4.164E-01	4.084E-01	4.062E-01	3.939E-01	3.814E-01	3.760E-01	3.687E-01	
3.675E-01	3.627E-01	3.590E-01	3.496E-01	3.460E-01	3.449E-01	3.427E-01	3.411E-01	
3.413E-01	3.373E-01	3.325E-01	3.292E-01	3.281E-01	3.268E-01	3.258E-01	3.253E-01	
3.276E-01	3.256E-01	3.243E-01	2.991E-01	2.980E-01	3.060E-01	3.014E-01	3.144E-01	
3.249E-01	3.173E-01	3.317E-01	3.340E-01	3.324E-01	3.401E-01	3.425E-01	3.056E-01	
2.879E-01	5.850E-02							

5.922E-03	5.972E-03	6.776E-03	5.850E-03	4.409E-03	4.146E-03	4.915E-03	7.097E-03
8.407E-03	8.752E-03	9.457E-03	9.710E-03	5.437E-03	5.491E-03	5.970E-03	6.802E-03
8.013E-03	1.593E-03	1.777E-03	2.094E-03	2.513E-03	3.216E-03	3.123E-03	3.108E-03
2.780E-03	2.603E-03	2.547E-03	1.595E-03	1.596E-03	1.576E-03	1.957E-03	1.969E-03
1.904E-03	1.620E-03	1.602E-03	1.275E-03	1.158E-03	1.087E-03	1.100E-03	1.080E-03
1.089E-03	1.158E-03	1.286E-03	1.406E-03	1.468E-03	1.114E-03	1.148E-03	1.144E-03
1.027E-03	9.429E-04	9.114E-04	9.717E-04	9.900E-04	1.065E-03	1.115E-03	1.110E-03
1.098E-03	1.431E-03	1.420E-03	1.354E-03	1.359E-03	1.316E-03	1.270E-03	1.212E-03
1.206E-03	1.104E-03	1.047E-03	1.025E-03	9.634E-04	8.996E-04	8.812E-04	8.098E-04
7.961E-04	7.666E-04	8.886E-04	8.519E-04	6.499E-04	6.073E-04	5.543E-04	5.312E-04
5.380E-04	3.808E-04	3.661E-04	2.695E-04	3.473E-04	3.542E-04	3.341E-04	2.659E-04
2.603E-04	1.786E-04	1.485E-04	1.976E-04	1.899E-04	1.102E-04	1.034E-04	4.705E-05
-2.017E-05	3.674E-05	-1.072E-04	-1.683E-04	-2.062E-04	-2.331E-04	-3.201E-04	-3.505E-04
-3.552E-04	-2.638E-04	-2.004E-04	-1.871E-04	3.150E-04	3.372E-04	3.425E-04	7.398E-05
6.016E-05	-5.306E-05	-1.338E-04	-9.428E-05	-2.561E-04	-2.810E-04	-4.098E-04	-4.644E-04
-4.930E-04	-3.864E-04	-3.086E-04	-2.372E-04	-2.226E-04	-2.529E-04	-2.597E-04	-2.825E-04
-2.516E-04	-1.742E-04	-1.853E-04	2.240E-03	2.289E-03	2.375E-03	2.396E-03	2.466E-03
1.956E-03	2.216E-03	1.269E-03	1.561E-03	7.757E-04	1.109E-03	1.097E-03	-1.235E-02
1.052E-02	6.078E-03						
C1: -1.141E+01	-5.845E+00	-5.997E+00	-6.113E+00	-5.696E+00	-5.673E+00	-5.718E+00	-5.293E+00
-4.867E+00	-4.845E+00	-4.799E+00	-4.788E+00	-4.805E+00	-4.793E+00	-4.775E+00	-4.758E+00
-4.737E+00	-4.904E+00	-4.899E+00	-4.826E+00	-4.747E+00	-4.534E+00	-4.451E+00	-4.421E+00
-4.392E+00	-4.360E+00	-4.347E+00	-4.337E+00	-4.302E+00	-4.269E+00	-4.165E+00	-4.153E+00
-4.043E+00	-3.965E+00	-3.956E+00	-3.900E+00	-3.874E+00	-3.817E+00	-3.761E+00	-3.721E+00
-3.642E+00	-3.610E+00	-3.559E+00	-3.519E+00	-3.497E+00	-3.448E+00	-3.415E+00	-3.405E+00
-3.368E+00	-3.347E+00	-3.329E+00	-3.259E+00	-3.242E+00	-3.181E+00	-3.128E+00	-3.105E+00
-3.032E+00	-2.847E+00	-2.834E+00	-2.779E+00	-2.757E+00	-2.699E+00	-2.681E+00	-2.624E+00
-2.612E+00	-2.549E+00	-2.463E+00	-2.439E+00	-2.396E+00	-2.349E+00	-2.337E+00	-2.282E+00
-2.257E+00	-2.223E+00	-2.075E+00	-2.063E+00	-2.004E+00	-1.989E+00	-1.935E+00	-1.881E+00
-1.869E+00	-1.793E+00	-1.773E+00	-1.708E+00	-1.610E+00	-1.594E+00	-1.502E+00	-1.448E+00
-1.432E+00	-1.378E+00	-1.322E+00	-1.221E+00	-1.218E+00	-1.164E+00	-1.152E+00	-1.110E+00
-1.086E+00	-1.062E+00	-1.016E+00	-9.734E-01	-9.434E-01	-9.291E-01	-9.044E-01	-8.887E-01
-8.749E-01	-8.291E-01	-7.890E-01	-7.775E-01	-7.201E-01	-6.552E-01	-6.259E-01	-5.749E-01
-5.683E-01	-5.400E-01	-5.208E-01	-4.819E-01	-4.656E-01	-4.611E-01	-4.494E-01	-4.436E-01
-4.418E-01	-4.330E-01	-4.187E-01	-4.085E-01	-4.047E-01	-4.003E-01	-3.963E-01	-3.945E-01
-4.087E-01	-4.050E-01	-4.057E-01	-3.489E-01	-3.474E-01	-3.891E-01	-3.859E-01	-4.788E-01
-5.458E-01	-5.676E-01	-6.294E-01	-6.566E-01	-6.504E-01	-7.124E-01	-7.275E-01	-3.130E-01
-6.437E-01	-9.121E+00						
C2: -1.598E+01	-1.259E+01	-1.279E+01	-1.298E+01	-5.685E+00	-5.660E+00	-5.722E+00	-5.400E+00
-5.012E+00	-4.984E+00	-4.939E+00	-4.912E+00	-4.940E+00	-4.926E+00	-4.892E+00	-4.862E+00
-4.835E+00	-5.016E+00	-5.007E+00	-4.925E+00	-4.834E+00	-4.654E+00	-4.575E+00	-4.544E+00
-4.517E+00	-4.481E+00	-4.468E+00	-4.446E+00	-4.409E+00	-4.374E+00	-4.258E+00	-4.245E+00
-4.127E+00	-4.011E+00	-4.002E+00	-3.940E+00	-3.914E+00	-3.855E+00	-3.800E+00	-3.759E+00
-3.681E+00	-3.648E+00	-3.597E+00	-3.556E+00	-3.533E+00	-3.459E+00	-3.424E+00	-3.413E+00
-3.378E+00	-3.358E+00	-3.341E+00	-3.278E+00	-3.261E+00	-3.199E+00	-3.147E+00	-3.124E+00
-3.055E+00	-2.874E+00	-2.863E+00	-2.810E+00	-2.788E+00	-2.728E+00	-2.710E+00	-2.653E+00
-2.640E+00	-2.576E+00	-2.486E+00	-2.460E+00	-2.416E+00	-2.371E+00	-2.359E+00	-2.304E+00
-2.278E+00	-2.245E+00	-2.123E+00	-2.112E+00	-2.057E+00	-2.045E+00	-1.995E+00	-1.940E+00
-1.927E+00	-1.850E+00	-1.830E+00	-1.769E+00	-1.663E+00	-1.645E+00	-1.545E+00	-1.487E+00
-1.469E+00	-1.405E+00	-1.338E+00	-1.231E+00	-1.228E+00	-1.162E+00	-1.147E+00	-1.094E+00
-1.062E+00	-1.038E+00	-9.820E-01	-9.268E-01	-8.909E-01	-8.750E-01	-8.521E-01	-8.304E-01
-8.121E-01	-7.576E-01	-7.142E-01	-7.019E-01	-6.491E-01	-5.806E-01	-5.494E-01	-4.896E-01
-4.829E-01	-4.523E-01	-4.218E-01	-3.719E-01	-3.515E-01	-3.475E-01	-3.406E-01	-3.361E-01
-3.393E-01	-3.328E-01	-3.244E-01	-3.185E-01	-3.173E-01	-3.206E-01	-3.243E-01	-3.286E-01
-3.673E-01	-3.683E-01	-3.801E-01	-3.312E-01	-3.349E-01	-3.968E-01	-3.929E-01	-4.686E-01
-5.120E-01	-5.228E-01	-6.046E-01	-6.408E-01	-6.754E-01	-7.437E-01	-7.587E-01	-5.208E-01
-9.290E-01	-9.168E+00						

C3: -1.607E+01	-1.264E+01	-1.285E+01	-1.303E+01	-5.621E+00	-5.609E+00	-5.670E+00	-5.313E+00
-4.918E+00	-4.922E+00	-4.876E+00	-4.846E+00	-4.866E+00	-4.856E+00	-4.835E+00	-4.828E+00
-4.795E+00	-4.951E+00	-4.932E+00	-4.865E+00	-4.784E+00	-4.586E+00	-4.513E+00	-4.482E+00
-4.455E+00	-4.433E+00	-4.419E+00	-4.412E+00	-4.378E+00	-4.346E+00	-4.231E+00	-4.220E+00
-4.116E+00	-4.014E+00	-4.003E+00	-3.941E+00	-3.917E+00	-3.860E+00	-3.806E+00	-3.767E+00
-3.686E+00	-3.654E+00	-3.601E+00	-3.558E+00	-3.535E+00	-3.475E+00	-3.439E+00	-3.427E+00
-3.382E+00	-3.357E+00	-3.337E+00	-3.269E+00	-3.252E+00	-3.192E+00	-3.139E+00	-3.116E+00
-3.045E+00	-2.856E+00	-2.843E+00	-2.788E+00	-2.765E+00	-2.697E+00	-2.676E+00	-2.610E+00
-2.595E+00	-2.522E+00	-2.434E+00	-2.409E+00	-2.365E+00	-2.317E+00	-2.303E+00	-2.241E+00
-2.212E+00	-2.172E+00	-1.990E+00	-1.977E+00	-1.910E+00	-1.893E+00	-1.833E+00	-1.769E+00
-1.754E+00	-1.669E+00	-1.648E+00	-1.573E+00	-1.493E+00	-1.476E+00	-1.384E+00	-1.336E+00
-1.322E+00	-1.272E+00	-1.223E+00	-1.139E+00	-1.136E+00	-1.086E+00	-1.073E+00	-1.033E+00
-1.009E+00	-9.928E-01	-9.508E-01	-9.146E-01	-8.932E-01	-8.833E-01	-8.748E-01	-8.608E-01
-8.471E-01	-8.039E-01	-7.699E-01	-7.597E-01	-7.145E-01	-6.563E-01	-6.314E-01	-6.036E-01
-6.003E-01	-5.870E-01	-5.727E-01	-5.361E-01	-5.134E-01	-5.086E-01	-4.977E-01	-4.915E-01
-4.922E-01	-4.793E-01	-4.625E-01	-4.517E-01	-4.482E-01	-4.441E-01	-4.389E-01	-4.352E-01
-4.461E-01	-4.394E-01	-4.376E-01	-3.783E-01	-3.745E-01	-4.114E-01	-3.976E-01	-4.681E-01
-5.235E-01	-5.262E-01	-6.026E-01	-6.317E-01	-6.439E-01	-6.997E-01	-7.156E-01	-5.017E-01
-8.063E-01	-9.180E+00						
C4: -1.606E+01	-1.258E+01	-1.281E+01	-1.298E+01	-5.914E+00	-5.884E+00	-5.955E+00	-5.359E+00
-4.860E+00	-4.819E+00	-4.776E+00	-4.690E+00	-4.702E+00	-4.691E+00	-4.675E+00	-4.663E+00
-4.646E+00	-4.781E+00	-4.773E+00	-4.696E+00	-4.600E+00	-4.388E+00	-4.305E+00	-4.269E+00
-4.237E+00	-4.216E+00	-4.204E+00	-4.178E+00	-4.145E+00	-4.109E+00	-4.024E+00	-4.013E+00
-3.903E+00	-3.803E+00	-3.794E+00	-3.734E+00	-3.708E+00	-3.659E+00	-3.605E+00	-3.570E+00
-3.496E+00	-3.465E+00	-3.417E+00	-3.379E+00	-3.358E+00	-3.290E+00	-3.259E+00	-3.248E+00
-3.209E+00	-3.186E+00	-3.167E+00	-3.100E+00	-3.083E+00	-3.025E+00	-2.972E+00	-2.950E+00
-2.883E+00	-2.684E+00	-2.671E+00	-2.618E+00	-2.597E+00	-2.541E+00	-2.524E+00	-2.467E+00
-2.454E+00	-2.390E+00	-2.324E+00	-2.300E+00	-2.260E+00	-2.216E+00	-2.204E+00	-2.145E+00
-2.118E+00	-2.078E+00	-1.956E+00	-1.945E+00	-1.888E+00	-1.874E+00	-1.822E+00	-1.771E+00
-1.759E+00	-1.680E+00	-1.660E+00	-1.597E+00	-1.511E+00	-1.495E+00	-1.407E+00	-1.356E+00
-1.339E+00	-1.279E+00	-1.218E+00	-1.121E+00	-1.118E+00	-1.061E+00	-1.047E+00	-1.002E+00
-9.756E-01	-9.590E-01	-9.125E-01	-8.725E-01	-8.456E-01	-8.314E-01	-8.135E-01	-7.962E-01
-7.820E-01	-7.407E-01	-7.049E-01	-6.951E-01	-6.552E-01	-5.920E-01	-5.649E-01	-5.172E-01
-5.104E-01	-4.829E-01	-4.653E-01	-4.324E-01	-4.153E-01	-4.116E-01	-4.019E-01	-3.988E-01
-4.043E-01	-4.011E-01	-3.917E-01	-3.866E-01	-3.863E-01	-3.964E-01	-4.021E-01	-4.053E-01
-4.327E-01	-4.342E-01	-4.383E-01	-4.144E-01	-4.182E-01	-4.841E-01	-4.828E-01	-5.604E-01
-6.185E-01	-6.326E-01	-6.995E-01	-7.263E-01	-7.136E-01	-7.746E-01	-7.875E-01	-3.844E-01
-7.539E-01	-9.069E+00						

Annexe-3: Nombre des points utilisés, valeurs de Sigma, a, b, c1, c2, c3, c4 pour 146 fréquences indiquée dans l'Annexe-1, pour l'ensemble des données iraniennes (composante verticale), pour d=1.0 .

Points	3.005E+00	4.005E+00	4.005E+00	4.005E+00	6.900E+01	6.900E+01	7.100E+01	1.500E+02
1.860E+02	2.220E+02	2.240E+02	2.600E+02	2.650E+02	2.680E+02	2.690E+02	2.790E+02	2.790E+02
2.790E+02	2.950E+02	2.970E+02	3.160E+02	3.200E+02	3.270E+02	3.270E+02	3.270E+02	3.270E+02
3.280E+02	3.300E+02	3.300E+02	3.330E+02	3.330E+02	3.330E+02	3.380E+02	3.380E+02	3.380E+02
3.380E+02	3.610E+02	3.610E+02	3.610E+02	3.610E+02	3.620E+02	3.620E+02	3.620E+02	3.620E+02
3.620E+02	3.620E+02	3.620E+02	3.620E+02	3.620E+02	3.750E+02	3.750E+02	3.750E+02	3.750E+02
3.750E+02	3.750E+02	3.750E+02	3.750E+02	3.750E+02	3.750E+02	3.750E+02	3.750E+02	3.750E+02
3.740E+02	4.060E+02	4.060E+02	4.060E+02	4.060E+02	4.060E+02	4.060E+02	4.060E+02	4.060E+02
4.060E+02	4.060E+02	4.100E+02	4.100E+02	4.100E+02	4.100E+02	4.100E+02	4.100E+02	4.100E+02
4.100E+02	4.110E+02	4.450E+02	4.450E+02	4.450E+02	4.450E+02	4.450E+02	4.450E+02	4.450E+02
4.450E+02	4.450E+02	4.450E+02	4.430E+02	4.570E+02	4.570E+02	4.570E+02	4.570E+02	4.570E+02
4.570E+02	4.570E+02	4.550E+02	4.600E+02	4.600E+02	4.600E+02	4.600E+02	4.600E+02	4.600E+02
4.600E+02	4.570E+02	4.570E+02	4.570E+02	4.570E+02	4.570E+02	4.540E+02	4.540E+02	4.540E+02
4.540E+02	4.540E+02	4.540E+02	4.540E+02	4.500E+02	4.520E+02	4.520E+02	4.480E+02	4.480E+02
4.480E+02	4.480E+02	4.370E+02	4.370E+02	4.310E+02	4.310E+02	4.310E+02	4.310E+02	4.310E+02
4.290E+02	4.290E+02	4.290E+02	4.290E+02	4.290E+02	4.290E+02	4.290E+02	4.290E+02	4.290E+02
4.080E+02	4.080E+02	4.080E+02	4.010E+02	4.010E+02	3.960E+02	3.950E+02	3.720E+02	3.720E+02
3.710E+02	3.590E+02	3.530E+02	3.530E+02	3.300E+02	3.290E+02	3.290E+02	4.400E+01	4.400E+01
4.300E+01	4.680E-03							
σ	1.136E+01	6.430E+00	6.567E+00	6.626E+00	3.728E-01	3.616E-01	3.664E-01	3.193E-01
3.612E-01	3.415E-01	3.435E-01	3.532E-01	3.602E-01	3.627E-01	3.586E-01	3.597E-01	3.597E-01
3.535E-01	3.584E-01	3.562E-01	3.766E-01	3.683E-01	3.704E-01	3.622E-01	3.599E-01	3.599E-01
3.584E-01	3.621E-01	3.613E-01	3.630E-01	3.640E-01	3.641E-01	3.675E-01	3.679E-01	3.679E-01
3.681E-01	3.866E-01	3.873E-01	3.903E-01	3.916E-01	3.965E-01	3.987E-01	3.976E-01	3.976E-01
3.946E-01	3.935E-01	3.929E-01	3.928E-01	3.930E-01	4.071E-01	4.078E-01	4.082E-01	4.082E-01
4.069E-01	4.053E-01	4.032E-01	4.022E-01	4.023E-01	4.037E-01	4.032E-01	4.029E-01	4.029E-01
4.009E-01	4.099E-01	4.102E-01	4.108E-01	4.104E-01	4.092E-01	4.094E-01	4.083E-01	4.083E-01
4.083E-01	4.083E-01	4.084E-01	4.080E-01	4.059E-01	4.009E-01	3.999E-01	3.959E-01	3.959E-01
3.945E-01	3.924E-01	3.880E-01	3.873E-01	3.853E-01	3.850E-01	3.844E-01	3.839E-01	3.839E-01
3.837E-01	3.846E-01	3.847E-01	3.814E-01	3.817E-01	3.814E-01	3.822E-01	3.826E-01	3.826E-01
3.826E-01	3.818E-01	3.825E-01	3.798E-01	3.797E-01	3.774E-01	3.772E-01	3.739E-01	3.739E-01
3.712E-01	3.696E-01	3.638E-01	3.648E-01	3.625E-01	3.612E-01	3.609E-01	3.618E-01	3.618E-01
3.624E-01	3.657E-01	3.676E-01	3.680E-01	3.658E-01	3.641E-01	3.633E-01	3.582E-01	3.582E-01
3.570E-01	3.545E-01	3.470E-01	3.481E-01	3.505E-01	3.505E-01	3.512E-01	3.515E-01	3.515E-01
3.526E-01	3.531E-01	3.526E-01	3.540E-01	3.549E-01	3.589E-01	3.610E-01	3.619E-01	3.619E-01
3.624E-01	3.619E-01	3.621E-01	3.566E-01	3.559E-01	3.624E-01	3.614E-01	3.645E-01	3.645E-01
3.636E-01	3.679E-01	3.720E-01	3.677E-01	3.708E-01	3.622E-01	3.612E-01	4.500E-01	4.500E-01
4.581E-01	1.715E-01							
α	-9.794E-01	8.795E-01	8.838E-01	9.215E-01	7.535E-01	7.770E-01	8.302E-01	7.638E-01
6.501E-01	6.559E-01	6.529E-01	6.393E-01	6.678E-01	6.662E-01	6.726E-01	6.745E-01	6.745E-01
6.868E-01	7.716E-01	7.757E-01	7.965E-01	8.036E-01	7.629E-01	7.666E-01	7.700E-01	7.700E-01
7.774E-01	7.887E-01	7.903E-01	8.032E-01	8.024E-01	7.972E-01	7.906E-01	7.904E-01	7.904E-01
7.989E-01	7.960E-01	7.960E-01	7.973E-01	7.984E-01	7.936E-01	7.886E-01	7.858E-01	7.858E-01
7.805E-01	7.762E-01	7.658E-01	7.601E-01	7.571E-01	7.534E-01	7.523E-01	7.519E-01	7.519E-01
7.496E-01	7.483E-01	7.466E-01	7.410E-01	7.397E-01	7.325E-01	7.247E-01	7.197E-01	7.197E-01
7.078E-01	6.816E-01	6.819E-01	6.778E-01	6.762E-01	6.733E-01	6.728E-01	6.679E-01	6.679E-01
6.656E-01	6.589E-01	6.498E-01	6.476E-01	6.424E-01	6.378E-01	6.362E-01	6.284E-01	6.284E-01
6.246E-01	6.187E-01	5.908E-01	5.871E-01	5.784E-01	5.766E-01	5.691E-01	5.596E-01	5.596E-01
5.580E-01	5.513E-01	5.488E-01	5.325E-01	5.152E-01	5.133E-01	5.067E-01	5.075E-01	5.075E-01
5.073E-01	5.040E-01	5.000E-01	4.886E-01	4.882E-01	4.787E-01	4.768E-01	4.722E-01	4.722E-01
4.695E-01	4.648E-01	4.601E-01	4.538E-01	4.468E-01	4.433E-01	4.412E-01	4.390E-01	4.390E-01
4.382E-01	4.353E-01	4.283E-01	4.264E-01	4.141E-01	4.062E-01	4.017E-01	3.862E-01	3.862E-01
3.842E-01	3.761E-01	3.709E-01	3.681E-01	3.684E-01	3.688E-01	3.661E-01	3.632E-01	3.632E-01
3.641E-01	3.642E-01	3.590E-01	3.533E-01	3.505E-01	3.418E-01	3.379E-01	3.353E-01	3.353E-01
3.417E-01	3.413E-01	3.420E-01	3.248E-01	3.239E-01	3.223E-01	3.152E-01	3.214E-01	3.214E-01
3.127E-01	3.105E-01	3.237E-01	3.221E-01	3.233E-01	3.267E-01	3.283E-01	2.250E-01	2.250E-01
1.520E-01	5.852E-02							

b	3.784E-03	5.087E-03	5.975E-03	4.481E-03	6.457E-03	5.985E-03	5.500E-03	6.662E-03
9.981E-03	1.002E-02	1.008E-02	1.020E-02	7.440E-03	8.008E-03	8.362E-03	8.432E-03	8.432E-03
8.838E-03	2.367E-03	2.754E-03	2.718E-03	2.726E-03	4.171E-03	4.161E-03	4.086E-03	4.086E-03
3.650E-03	3.473E-03	3.425E-03	2.923E-03	2.850E-03	2.856E-03	2.998E-03	2.980E-03	2.980E-03
2.411E-03	2.269E-03	2.279E-03	2.153E-03	2.127E-03	2.264E-03	2.228E-03	2.221E-03	2.221E-03
2.038E-03	2.025E-03	2.156E-03	2.202E-03	2.264E-03	1.999E-03	1.994E-03	1.990E-03	1.990E-03
1.914E-03	1.876E-03	1.871E-03	1.890E-03	1.890E-03	1.997E-03	2.160E-03	2.248E-03	2.248E-03
2.428E-03	2.538E-03	2.495E-03	2.458E-03	2.444E-03	2.380E-03	2.341E-03	2.242E-03	2.242E-03
2.260E-03	2.246E-03	2.157E-03	2.092E-03	2.027E-03	1.965E-03	1.959E-03	1.928E-03	1.928E-03
1.935E-03	1.943E-03	2.160E-03	2.186E-03	2.040E-03	1.991E-03	1.832E-03	1.943E-03	1.943E-03
1.957E-03	1.785E-03	1.770E-03	2.102E-03	2.318E-03	2.319E-03	2.181E-03	1.938E-03	1.938E-03
1.872E-03	1.625E-03	1.338E-03	1.160E-03	1.155E-03	1.111E-03	1.077E-03	1.004E-03	1.004E-03
9.356E-04	1.128E-03	9.561E-04	8.501E-04	9.108E-04	9.391E-04	8.429E-04	7.535E-04	7.535E-04
6.815E-04	4.574E-04	3.800E-04	3.590E-04	7.233E-04	5.603E-04	4.873E-04	4.422E-04	4.422E-04
3.852E-04	2.992E-04	2.136E-04	-3.012E-06	-3.265E-04	-4.064E-04	-5.008E-04	-4.762E-04	-4.762E-04
-5.632E-04	-7.099E-04	-7.623E-04	-6.751E-04	-6.496E-04	-5.143E-04	-4.806E-04	-4.417E-04	-4.417E-04
-5.838E-04	-6.642E-04	-7.485E-04	9.246E-04	8.727E-04	7.052E-04	6.314E-04	2.161E-04	2.161E-04
8.757E-05	-2.157E-04	-1.166E-03	-7.606E-04	-2.473E-03	-2.058E-03	-1.965E-03	-1.214E-02	-1.214E-02
1.075E-02	6.078E-03							
C1:	7.009E+00	-6.500E+00	-6.403E+00	-6.489E+00	-5.304E+00	-5.342E+00	-5.506E+00	-5.151E+00
-4.635E+00	-4.652E+00	-4.600E+00	-4.494E+00	-4.547E+00	-4.526E+00	-4.528E+00	-4.510E+00	-4.510E+00
-4.533E+00	-4.755E+00	-4.759E+00	-4.806E+00	-4.785E+00	-4.572E+00	-4.541E+00	-4.526E+00	-4.526E+00
-4.518E+00	-4.529E+00	-4.523E+00	-4.530E+00	-4.495E+00	-4.443E+00	-4.356E+00	-4.346E+00	-4.346E+00
-4.293E+00	-4.188E+00	-4.181E+00	-4.140E+00	-4.130E+00	-4.079E+00	-4.018E+00	-3.985E+00	-3.985E+00
-3.923E+00	-3.891E+00	-3.828E+00	-3.788E+00	-3.769E+00	-3.726E+00	-3.703E+00	-3.695E+00	-3.695E+00
-3.658E+00	-3.636E+00	-3.617E+00	-3.565E+00	-3.553E+00	-3.504E+00	-3.452E+00	-3.422E+00	-3.422E+00
-3.340E+00	-3.180E+00	-3.172E+00	-3.121E+00	-3.104E+00	-3.070E+00	-3.060E+00	-3.013E+00	-3.013E+00
-2.997E+00	-2.939E+00	-2.870E+00	-2.851E+00	-2.813E+00	-2.775E+00	-2.761E+00	-2.702E+00	-2.702E+00
-2.676E+00	-2.637E+00	-2.465E+00	-2.444E+00	-2.375E+00	-2.360E+00	-2.302E+00	-2.233E+00	-2.233E+00
-2.219E+00	-2.147E+00	-2.127E+00	-2.039E+00	-1.937E+00	-1.923E+00	-1.853E+00	-1.827E+00	-1.827E+00
-1.817E+00	-1.765E+00	-1.710E+00	-1.617E+00	-1.614E+00	-1.544E+00	-1.529E+00	-1.489E+00	-1.489E+00
-1.465E+00	-1.436E+00	-1.394E+00	-1.346E+00	-1.306E+00	-1.285E+00	-1.252E+00	-1.229E+00	-1.229E+00
-1.214E+00	-1.174E+00	-1.125E+00	-1.112E+00	-1.045E+00	-9.830E-01	-9.540E-01	-8.631E-01	-8.631E-01
-8.499E-01	-7.971E-01	-7.642E-01	-7.389E-01	-7.268E-01	-7.250E-01	-7.050E-01	-6.910E-01	-6.910E-01
-6.887E-01	-6.834E-01	-6.582E-01	-6.352E-01	-6.247E-01	-5.932E-01	-5.781E-01	-5.679E-01	-5.679E-01
-5.994E-01	-5.975E-01	-6.089E-01	-5.758E-01	-5.764E-01	-5.828E-01	-5.631E-01	-6.105E-01	-6.105E-01
-5.868E-01	-6.282E-01	-6.956E-01	-7.141E-01	-6.980E-01	-7.464E-01	-7.643E-01	-1.183E-01	-1.183E-01
-2.848E-01	-9.121E+00							
C2:	-4.347E+00	-1.292E+01	-1.296E+01	-1.310E+01	-5.362E+00	-5.414E+00	-5.566E+00	-5.272E+00
-4.806E+00	-4.805E+00	-4.767E+00	-4.656E+00	-4.717E+00	-4.702E+00	-4.686E+00	-4.653E+00	-4.653E+00
-4.656E+00	-4.879E+00	-4.886E+00	-4.914E+00	-4.899E+00	-4.705E+00	-4.668E+00	-4.656E+00	-4.656E+00
-4.643E+00	-4.637E+00	-4.627E+00	-4.607E+00	-4.574E+00	-4.522E+00	-4.451E+00	-4.444E+00	-4.444E+00
-4.396E+00	-4.259E+00	-4.251E+00	-4.206E+00	-4.192E+00	-4.133E+00	-4.080E+00	-4.051E+00	-4.051E+00
-3.989E+00	-3.950E+00	-3.884E+00	-3.844E+00	-3.822E+00	-3.739E+00	-3.713E+00	-3.706E+00	-3.706E+00
-3.670E+00	-3.648E+00	-3.631E+00	-3.577E+00	-3.565E+00	-3.514E+00	-3.466E+00	-3.438E+00	-3.438E+00
-3.355E+00	-3.196E+00	-3.188E+00	-3.135E+00	-3.117E+00	-3.073E+00	-3.060E+00	-3.003E+00	-3.003E+00
-2.985E+00	-2.916E+00	-2.837E+00	-2.815E+00	-2.774E+00	-2.735E+00	-2.723E+00	-2.674E+00	-2.674E+00
-2.653E+00	-2.620E+00	-2.478E+00	-2.455E+00	-2.385E+00	-2.371E+00	-2.311E+00	-2.251E+00	-2.251E+00
-2.241E+00	-2.187E+00	-2.169E+00	-2.083E+00	-1.982E+00	-1.969E+00	-1.913E+00	-1.899E+00	-1.899E+00
-1.892E+00	-1.850E+00	-1.803E+00	-1.725E+00	-1.722E+00	-1.654E+00	-1.638E+00	-1.589E+00	-1.589E+00
-1.559E+00	-1.529E+00	-1.475E+00	-1.427E+00	-1.380E+00	-1.358E+00	-1.332E+00	-1.312E+00	-1.312E+00
-1.299E+00	-1.269E+00	-1.226E+00	-1.215E+00	-1.155E+00	-1.095E+00	-1.064E+00	-9.611E-01	-9.611E-01
-9.442E-01	-8.745E-01	-8.150E-01	-7.664E-01	-7.413E-01	-7.362E-01	-7.119E-01	-6.951E-01	-6.951E-01
-6.958E-01	-6.903E-01	-6.614E-01	-6.373E-01	-6.252E-01	-5.924E-01	-5.805E-01	-5.736E-01	-5.736E-01
-6.109E-01	-6.073E-01	-6.045E-01	-5.660E-01	-5.675E-01	-5.748E-01	-5.567E-01	-5.759E-01	-5.759E-01
-5.411E-01	-5.913E-01	-6.926E-01	-7.082E-01	-7.240E-01	-7.814E-01	-7.996E-01	-4.868E-01	-4.868E-01
-6.870E-01	-9.168E+00							

C3:	-4.290E+00	-1.297E+01	-1.301E+01	-1.315E+01	-5.262E+00	-5.310E+00	-5.506E+00	-5.230E+00
-4.741E+00	-4.780E+00	-4.725E+00	-4.605E+00	-4.651E+00	-4.626E+00	-4.615E+00	-4.609E+00	
-4.632E+00	-4.843E+00	-4.838E+00	-4.869E+00	-4.849E+00	-4.647E+00	-4.614E+00	-4.602E+00	
-4.585E+00	-4.599E+00	-4.591E+00	-4.583E+00	-4.557E+00	-4.517E+00	-4.431E+00	-4.423E+00	
-4.387E+00	-4.290E+00	-4.284E+00	-4.243E+00	-4.233E+00	-4.184E+00	-4.134E+00	-4.102E+00	
-4.033E+00	-4.000E+00	-3.936E+00	-3.900E+00	-3.883E+00	-3.840E+00	-3.817E+00	-3.809E+00	
-3.773E+00	-3.751E+00	-3.731E+00	-3.677E+00	-3.666E+00	-3.620E+00	-3.569E+00	-3.538E+00	
-3.455E+00	-3.308E+00	-3.302E+00	-3.251E+00	-3.234E+00	-3.187E+00	-3.172E+00	-3.112E+00	
-3.093E+00	-3.018E+00	-2.932E+00	-2.909E+00	-2.858E+00	-2.807E+00	-2.792E+00	-2.725E+00	
-2.696E+00	-2.652E+00	-2.472E+00	-2.449E+00	-2.371E+00	-2.353E+00	-2.286E+00	-2.218E+00	
-2.205E+00	-2.127E+00	-2.104E+00	-1.998E+00	-1.908E+00	-1.894E+00	-1.826E+00	-1.796E+00	
-1.785E+00	-1.732E+00	-1.684E+00	-1.600E+00	-1.597E+00	-1.524E+00	-1.509E+00	-1.468E+00	
-1.440E+00	-1.407E+00	-1.351E+00	-1.295E+00	-1.250E+00	-1.227E+00	-1.200E+00	-1.182E+00	
-1.170E+00	-1.137E+00	-1.094E+00	-1.083E+00	-1.021E+00	-9.563E-01	-9.226E-01	-8.316E-01	
-8.187E-01	-7.730E-01	-7.401E-01	-7.324E-01	-7.299E-01	-7.292E-01	-7.185E-01	-7.117E-01	
-7.178E-01	-7.288E-01	-7.166E-01	-6.997E-01	-6.914E-01	-6.572E-01	-6.414E-01	-6.308E-01	
-6.512E-01	-6.440E-01	-6.422E-01	-6.009E-01	-5.961E-01	-5.891E-01	-5.593E-01	-5.978E-01	
-5.924E-01	-6.062E-01	-6.649E-01	-6.809E-01	-6.973E-01	-7.474E-01	-7.633E-01	-2.578E-01	
-3.916E-01	-9.180E+00							
C4:	-4.077E+00	-1.291E+01	-1.296E+01	-1.308E+01	-5.653E+00	-5.694E+00	-5.830E+00	-5.280E+00
-4.745E+00	-4.707E+00	-4.658E+00	-4.460E+00	-4.518E+00	-4.497E+00	-4.484E+00	-4.455E+00	
-4.476E+00	-4.653E+00	-4.659E+00	-4.730E+00	-4.732E+00	-4.569E+00	-4.550E+00	-4.544E+00	
-4.522E+00	-4.531E+00	-4.526E+00	-4.526E+00	-4.496E+00	-4.451E+00	-4.411E+00	-4.407E+00	
-4.373E+00	-4.272E+00	-4.266E+00	-4.234E+00	-4.223E+00	-4.193E+00	-4.143E+00	-4.118E+00	
-4.048E+00	-4.010E+00	-3.937E+00	-3.896E+00	-3.875E+00	-3.802E+00	-3.779E+00	-3.772E+00	
-3.735E+00	-3.714E+00	-3.693E+00	-3.646E+00	-3.637E+00	-3.592E+00	-3.546E+00	-3.518E+00	
-3.438E+00	-3.265E+00	-3.258E+00	-3.211E+00	-3.194E+00	-3.153E+00	-3.140E+00	-3.088E+00	
-3.072E+00	-3.002E+00	-2.928E+00	-2.905E+00	-2.858E+00	-2.809E+00	-2.796E+00	-2.730E+00	
-2.701E+00	-2.654E+00	-2.506E+00	-2.481E+00	-2.387E+00	-2.368E+00	-2.305E+00	-2.243E+00	
-2.230E+00	-2.160E+00	-2.140E+00	-2.045E+00	-1.928E+00	-1.911E+00	-1.841E+00	-1.816E+00	
-1.806E+00	-1.749E+00	-1.687E+00	-1.587E+00	-1.583E+00	-1.500E+00	-1.484E+00	-1.441E+00	
-1.414E+00	-1.388E+00	-1.335E+00	-1.284E+00	-1.239E+00	-1.215E+00	-1.186E+00	-1.166E+00	
-1.155E+00	-1.124E+00	-1.082E+00	-1.069E+00	-1.012E+00	-9.487E-01	-9.166E-01	-8.247E-01	
-8.091E-01	-7.373E-01	-6.843E-01	-6.545E-01	-6.477E-01	-6.503E-01	-6.451E-01	-6.378E-01	
-6.416E-01	-6.368E-01	-6.046E-01	-5.772E-01	-5.655E-01	-5.338E-01	-5.182E-01	-5.067E-01	
-5.285E-01	-5.292E-01	-5.438E-01	-5.430E-01	-5.506E-01	-5.615E-01	-5.459E-01	-5.678E-01	
-5.506E-01	-5.944E-01	-6.868E-01	-7.142E-01	-7.068E-01	-7.629E-01	-7.763E-01	-1.959E-01	
-3.651E-01	-9.069E+00							

Annexe-4: Base des données de ce mémoire.

No	Record	Station	Site	Date	Mw	R(km)	Kh	Kv	Stress Drop (Bar)	Fc Corner freq. Hz	fmax (H) Hz	fmax (V) Hz	Dur (H1) sec	Dur (V) sec	Dur (H2) sec	Arms (H1) m/s	Arms (V) m/s	Arms (H2) m/s	Ea (H1) m2/s3	Ea (V) m2/s3	Ea (H2) m2/s3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	Vmax (H1) m/sec	Vmax (V) m/sec	Vmax (H2) m/sec	Dmax (H1) m	Dmax (V) m	Dmax (H2) m	
1	1012	Kiasar	2	05/11/74	4.5	64							1.53	5.22	1.56	1400	0320	1200	0340	0058	0240	390	157	300							
2	1006-1	Bandarabbas	2	07/03/75	6.1	48							15.04	20.25	11.38	2300	1100	3300	8700	2900	1400	863	417	1.287	0.629	0.329	0.847				
3	1006-2	Bandarabbas	2	07/03/75	5.2	40							16.33	16.27	14.43	0430	0370	0530	0330	0250	0450	167	125	260							
4	1007	Minab	1	07/03/75	6.1	80							16.02	17.51	18.23	0410	0260	0350	0290	0140	0250	217	094	168							
5	1008	Gheshm Island	1	07/03/75	6.1	56							25.60	20.13	22.57	0370	0360	0360	0390	0280	0320	148	137	121							
6	1013	Tonkabon	4	13/03/75	4.4	34							5.83	10.53	7.72	0890	0210	0630	0510	0051	0340	428	102	192							
7	1009	Minab	1	12/04/75	4.8	48							11.19	17.34	14.70	0660	0200	0390	0540	0074	0250	357	077	154							
8	1026	Shiraz	4	02/06/75	4.1	60							3.64	3.78	6.71	0900	0610	0370	0320	0150	0100	505	286	251							
9	1014-4	Hajjiabad	3	08/10/75	5.4	32							14.53	11.88	15.17	1800	1100	1600	5300	1700	4500	689	471	796							
10	1024	Maraveh-	3	27/12/75	4.6	6							2.76	2.56	2.63	7400	3700	8000	17000	4000	1900	3270	1.533	3.595	0.717	0.234	0.0968				
11	1034-1	Maku	2	27/02/76	3.9	26							2.38	1.92	2.35	1300	0970	1300	0430	0200	0460	432	316	537	0.119	0.084	0.144				
12	1034-2	Maku	2	02/04/76	4.6	12							68	2.58	1.88	6600	1900	2900	3300	0980	1800	1997	845	1.022							
13	1040-3	Naghan-1	1	05/09/76	4.7	88							1.28	1.58	1.49	1200	1400	1200	0200	0320	0220	437	452	495	0.090	0.170	0.169	0.00460	0.01400	0.01300	
14	1043	Ghaen	1	07/11/76	6.4	10	0.240	0.308	262.7	0.35			11.20	7.82	10.58	3100	3900	3500	12000	13000	1400	1.150	1.700	1.570	0.110	0.028	0.065				
15	1047-8	Vendik	2	07/11/76	6.4	11							11	60	13	2.800	4200	2200	9800	1200	7200	5.117	1.167	4.982	0.742	0.223	0.571				
16	1047-9	Vendik	2	07/11/76	4.8	9							30	55	52	5800	2200	4900	1100	0290	1400	1.750	674	1.559	0.164	0.053	0.160	0.003370	0.00234	0.000560	
17	1047-10	Vendik	2	09/11/76	5.1	5							66	58	71	2100	2500	0320	0390	0510	602	920	978	0.122	0.199	0.066	0.00270	0.00190	0.000680		
18	1046-1	Maku	2	24/11/76	7.3	48							16.07	20.10	20.40	1600	0690	1300	4900	1000	3600	891	455	685							
19	1046-2	Maku	2	24/11/76	5.5	47							7.61	9.57	7.02	1400	0430	1300	1600	0190	1300	718	212	408							
20	1049-1	Siah-Cheshmeh	1	06/12/76	4.4	3	0.075	0.027	194.1	1.0			7.05	9.72	7.38	0880	0530	1000	0610	0300	0870	402	153	337							
21	1049-2	Siah-Cheshmeh	1	06/12/76	4.4	19	0.089	0.029	164.7	1.5			6.10	8.74	5.78	0350	0190	0580	0081	0036	0220	119	082	166							
22	1049-3	Siah-Cheshmeh	1	12/12/76	4.8	14	0.075		116.6	1.5			6.11	8.35	6.42	0260	0150	0380	0046	0020	0110	081	053	134							
23	1050-1	Bandarabbas	2	21/03/77	7.0	52							21.56	27.32	17.98	2200	1100	3000	12000	3700	1700	973	379	1.504	0.556	0.275	0.768				
24	1052	Gheshm-Island	1	21/03/77	7.0	71							7.75	7.44	7.55	0750	0520	0740	0490	0220	0460	184	149	266							
25	1054-1	Naghan-1	1	06/04/77	6.1	7							2.78	3.18	2.70	2.500	1.600	1.900	19.000	8.8000	11.00	7.200	5.200	6.150	4.600	5.400	3.800	0.10000	0.10200	0.03200	
26	1055	Farsan	1	06/04/77	6.1	32							14.00	12.59	13.59	0490	0280	0560	0370	0110	0480	155	093	180							
27	1058	Dastgerd	2	06/04/77	6.1	18							3.95	5.08	4.16	2300	1300	2300	2200	1000	2500	981	493	816							
28	1059	Ardal	4	06/04/77	6.1	21							1.62	5.32	3.02	1800	0480	1300	0600	0130	0540	685	477	623							
29	1056-5	Naghan-1	1	12/04/77	4.9	15							44	2.41	1.75	1800	0420	0790	0150	0047	0120	649	219	370	0.072	0.059	0.084				
30	1060-2	Naghan-1	1	04/05/77	4.8	20	0.016	0.029	164.7	1.5	18.0	18.0	3.21	2.64	5.02	0340	0510	0310	0040	0076	0054	127	168	159							
31	1080-8	Naghan-1	1	21/10/77	5.0	19	0.032	0.038	335.5	1.2	8.0	8.0	3.39	5.24	3.06	2200	1600	2900	1900	1400	2900	1.056	780	1.587							
32	1092-1	Aghajari	2	31/03/78	4.4	30							2.56	5.90	1.70	0700	0210	1200	0140	0028	0260	442	183	640	0.066	0.028	0.072				
33	1080-10	Naghan-1	1	12/04/78	4.9	15							1.19	1.01	96	2400	3100	3300	0780	1100	1200	720	1.019	1.061							
34	1080-11	Naghan-1	1	20/05/78	5.0	28							1.39	1.32	2.64	1100	1100	0670	0180	0180	0130	513	572	360							
35	1080-12	Naghan-1	1	11/08/78	4.3	30							56	1.12	53	2800	1100	2800	0500	0140	0460	1.171	417	1.137							
36	1094-1	Kazerun	2	29/08/78	4.9	12							7.63	7.05	4.71	0840	0390	1700	0600	0120	1600	408	160	826							
37	1082-1	Deyhuk	1	16/09/78	7.4	36							34.01	30.20	34.91	4900	3600	5000	9.0000	4.2000	9.700	3.204	1.618	3.757	0.1758	0.1183	2400	040002	027052	059408	
38	1083-1	Boshruyeh	1	16/09/78	7.4	64							21.58	24.34	22.56	2700	2100	2600	1.7000	1.2000	1.700	980	870	940	0.980	0.780	1.140	0.01900	0.01600	0.02300	
39	1084-1	Tabas	1	16/09/78	7.4	27							16.56	14.88	18.30	1.900	1.400	1.800	66.000	32.000	66.00	11.030	8.480	8.410	1.1300	3600	9700	900000	120000	355000	
40	1086	Bajestan	3	16/09/78	7.4	140							27.64	31.10	26.36	1500	0470	1500	7000	0750	6800	795	159	581	0.457	0.145	0.318				
41	1090-2	Kashmar	3	16/09/78	7.4	234							29.66	25.52	27.62	1100	0780	1200	3700	1700	4600	321	246	394							
42	1082-6	Deyhuk	1	17/09/78	4.7	53							97	2.34	1.04	1700	0740	1300	0310	0140	0210	676	390	440							
43	1103-1	Tabas	1	24/09/78	4.5	22							3.59	4.88	2.39	0560	0360	0890	0120	0070	0210	226	301	421	0.048	0.033	0.077				
44	1104-2	Deyhuk	1	24/09/78	4.5	42							76	3.79	5.26	1700	0450	0550	0260	0086	0180	500	280	355	0.204	0.069	0.164				
45	1093-2	Khonj	1	12/10/78	4.2	75	0.046	0.024	555.	7.0	11.0	18.0	3.69	4.67	4.30	0570	0480	0660	0130	0120	0210	323	188	234							
46	1103-3	Tabas	1	12/10/78	4.9	20							3.50	8.28	2.67	1400	0530	2200	0770	0250	1500	659	343	1.052	0.167	0.066	0.308				
47	1098-3	Talesh	3	04/11/78	6.2	20							4.38	5.42	4.20	1100	0720	1000	0570	0310	0470	556	287	517	0.140	0.072	0.127				
48	1096-1	Naghan-1	1	14/12/78	6.1	5							57	78	88	2600	2500	2600	0440	0540	0630	710	754	807	0.110	0.108	0.452				
49	1096-2	Naghan-1	1	14/12/78	4.7	5							1.87	1.98	26	0480	0440	3000	0047	0043	0270	252	226	668	0.030	0.030	0.077				
50	1097-2	Naghan-2	1	14/12/78	4.7	5							22	75	3.91	3300	1300	0430	0270	0140	0081	812	454	359	0.091	0.138	0.052				
51	1103-9	Tabas	1	26/12/78	4.5	21							4.42	5.86	4.24	0590	0410	1100	0170	0110	0600	277	176	853	0.057	0.048	0.166				
52	11																														

No	Record	Station	Site	Date	Mw	R(km)	Kh	Kv	Stress Drop (Bar)	Fc Corner freq. Hz	fmax (H) Hz	fmax (V) Hz	Dur (H1) sec	Dur (V) sec	Dur (H2) sec	Arms (H1) m/s	Arms (H2) m/s	Arms (H3) m/s	Ea (H1) m2/s3	Ea (V) m2/s3	Ea (H2) m2/s3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	Vmax (H1) m/sec	Vmax (V) m/sec	Vmax (H2) m/sec	Dmax (H1) m	Dmax (V) m	Dmax (H2) m	
112	1240-4	Ghir	3	02/02/85	4.5	18							4.29	3.28	5.38	0.390	0.250	0.290	0.0071	0.0023	0.0051	0.233	0.107	0.197							
113	1240-6	Ghir	3	02/02/85	5.2	7							3.27	4.43	3.75	0.3400	0.1500	0.2600	0.1100	0.2800	0.1852	0.802	0.1552	0.0183	0.0091	0.0127					
114	1247-1	Avaj	1	09/05/85	3.1	9	0.062	0.047	83.2	3.0	11.0	15.0	2.29	2.96	4.07	0.1300	0.0800	0.0680	0.0210	0.0150	0.045	0.309	0.303	0.115	0.0045	0.0051					
115	1291-1	Kazerun	2	12/07/86	5.7	45							5.86	7.53	5.75	0.0760	0.0270	0.0690	0.0380	0.0061	0.0300	0.330	0.105	0.284							
116	1308	Bandar-lengeh	3	09/08/86	5.1	23							5.88	6.61	5.05	0.1100	0.0690	0.1800	0.0800	0.0350	0.1800	0.366	0.271	0.656	0.0151	0.0087	0.0211	0.000590	0.000500	0.000965	
117	1289-1	Noorabad-Mamassani	3	10/10/86	4.3	32							5.34	10.01	7.05	0.0780	0.0260	0.0610	0.0370	0.0076	0.0290	0.275	0.123	0.278							
118	1289-3	Noorabad-Mamassani	3	10/10/86	4.9	32							4.96	7.97	5.87	0.2600	0.0860	0.2200	0.3600	0.0650	0.3100	1.014	0.497	0.788	0.0220	0.0087	0.0245	0.000575	0.000263	0.000920	
119	1289-2	Noorabad-Mamassani	3	18/10/86	4.9	13							6.52	9.01	7.49	0.1500	0.0660	0.1100	0.1700	0.0440	0.1100	0.644	0.294	0.445	0.0158	0.0051	0.0140	0.000449	0.000117	0.000415	
120	1289-4	Noorabad-Mamassani	3	20/11/86	5.2	24							7.44	14.30	8.14	0.2300	0.0740	0.2000	0.4400	0.0870	0.3600	1.004	0.494	0.608	0.0250	0.0066	0.0168	0.000757	0.000189	0.000596	
121	1289-5	Noorabad-Mamassani	3	20/12/86	5.5	24							7.80	12.30	11.69	0.0850	0.0340	0.0450	0.0630	0.0160	0.0270	0.365	0.147	0.208	0.0080	0.0029	0.0028				
122	1311-1	Old Lar	1	16/01/87	4.5	16							7.38	7.91	8.60	0.0760	0.0670	0.0680	0.0470	0.0390	0.0440	0.320	0.282	0.353	0.0070	0.0053	0.0053	0.000189	0.000110	0.000125	
123	1311-2	Old Lar	1	19/01/87	4.0	24							7.86	7.19	6.68	0.0390	0.0340	0.0490	0.0140	0.0095	0.0180	0.171	0.147	0.331							
124	1319-1	Naghan-2	1	20/01/87	4.6	4	0.046	0.041	41.4	1.5	20.0	20.0	2.23	1.91	2.74	0.1700	0.1900	0.1300	0.0760	0.0800	0.0530	1.174	0.914	0.648	0.0175	0.0156	0.0155	0.000890	0.000684	0.000899	
125	1320-2	Naghan-1	1	20/01/87	4.6	6							1.43	1.26	1.10	0.1900	0.2300	0.2900	0.0570	0.0760	0.1000	0.643	0.832	1.062	0.0141	0.0114	0.0232	0.000664	0.000354	0.000825	
126	1319-2	Naghan-2	1	12/03/87	4.3	64							0.88	1.25	1.42	0.3300	0.2000	0.2000	0.3300	0.0780	0.2600	1.009	0.488	0.733	0.0393	0.0142	0.0257	0.001783	0.000638	0.001193	
127	1305	Kuhbanan	3	11/04/87	5.0	4							4.69	7.69	4.54	0.2500	0.0950	0.2300	0.3300	0.0780	0.2600	1.009	0.488	0.733	0.0393	0.0142	0.0257	0.001783	0.000638	0.001193	
128	1307	Sirch	1	22/04/87	4.6	24							3.17	3.85	3.91	0.1000	0.0630	0.1000	0.0370	0.0170	0.0460	0.535	0.311	0.580	0.0137	0.0057	0.0083	0.000443	0.000233	0.000309	
129	1303	Bostan-abad	4	22/07/87	4.2	10							5.20	5.57	6.09	0.3400	0.1200	0.2200	0.6900	0.0850	0.3300	1.286	0.322	0.796	0.0582	0.0141	0.0353	0.003016	0.000703	0.001842	
130	1300-1	Birjand	1	24/11/87	5.3	8							8.07	9.28	7.48	0.1700	0.1500	0.1600	0.2500	0.2200	0.2200	0.642	0.477	0.492	0.0484	0.0335	0.0296	0.005998	0.005025	0.003816	
131	1300-3	Birjand	1	27/11/87	4.7	20							9.03	9.67	8.06	0.0330	0.0330	0.0340	0.0110	0.0120	0.0110	0.097	0.115	0.107							
132	1351	Tehran (Sharif University)	1	20/06/90	7.3	210							14.51	11.66	12.76	0.0250	0.0470	0.0300	0.0097	0.0280	0.0130	0.105	0.251	0.116							
133	1353	Ghazvin	3	20/06/90	7.3	76							18.04	26.46	24.50	0.3600	0.2200	0.2900	0.6000	1.4000	2.300	1.860	0.900	1.340	0.1540	0.0760	0.1170	0.039000	0.028000	0.030000	
134	1354	Abhar	4	20/06/90	7.3	80							22.73	23.61	19.13	0.3800	0.1700	0.5900	0.3700	0.8000	1.400	1.282	0.728	1.906							
135	1355	Rudbar	4	20/06/90	7.3	68							29.06	27.86	27.28	0.2300	0.1600	0.2100	0.7000	0.7600	1.400	0.892	0.737	0.688	0.1000	0.0473	0.0884				
136	1357-1	Lahijan	4	20/06/90	7.3	96							33.96	32.62	27.72	0.2700	0.1800	0.4600	0.2800	1.2000	0.6000	1.080	0.750	1.760	0.1350	0.0730	0.3630	0.071000	0.041500	0.155000	
137	1359	Tonkabon	4	20/06/90	7.3	100							18.40	24.69	26.25	0.3000	0.0700	0.2100	0.9000	0.3300	1.200	1.173	0.303	0.727							
138	1360	Manjil	2	20/06/90	7.3	12	0.049	0.029	194.1	1.0	10.0	18.0	1.61	2.23	1.83	0.1500	0.4900	0.1100	0.3800	0.5900	2.400	4.382	1.712	3.958	0.0937	0.0389	0.0941				
139	1361	Gachsar	3	20/06/90	7.3	176							32.43	33.47	33.27	0.1200	0.0730	0.1600	0.4800	0.2000	0.9700	0.499	0.388	0.951							
140	1362-1	Abbar	1	20/06/90	7.3	40							31.92	35.96	35.06	0.3300	0.1900	0.5900	0.2500	1.4000	0.3300	0.5260	0.5480	0.5030	0.3800	0.4840	0.4360	0.163000	0.040000	0.203000	
141	1363-1	Kahrizak	4	20/06/90	7.3	224							15.14	14.58	15.14	0.1400	0.0830	0.1400	0.3500	0.1100	0.3500	0.460	0.280	0.350	0.0710	0.0280	0.0600	0.015000	0.007000	0.015000	
142	1364	Zanjan	1	20/06/90	7.3	80							35.84	40.92	39.96	0.2100	0.1100	0.1500	0.1800	0.1000	0.2500	0.770	0.300	0.150	0.290	0.0350	0.0290	0.0260	0.006600	0.005700	0.004900
143	1365	Ardebil	4	20/06/90	7.3	195							8.28	8.98	9.02	0.1100	0.0500	0.0880	0.1000	0.0250	0.0770	0.300	0.189	0.133							
144	1366	Tehran (Chizar)	1	20/06/90	7.3	212							17.92	14.74	18.58	0.0440	0.0480	0.0380	0.0390	0.0370	0.0290	0.140	0.320	0.440	0.0420	0.0480	0.0620	0.008800	0.013000	0.016000	
145	1369	Rudshur	4	20/06/90	7.3	198							14.42	12.10	13.84	0.1000	0.1000	0.1400	0.1800	0.1500	0.2900	0.400	0.320	0.440	0.0420	0.0480	0.0620	0.008800	0.013000	0.016000	
146	1370-2	Robot-Karim	1	20/06/90	7.3	207							16.20	15.74	17.52	0.0290	0.0590	0.0390	0.0150	0.0600	0.0290	0.130	0.190	0.170	0.0088	0.0124	0.0105	0.001000	0.001600	0.001500	
147	1371-2	Karaj	1	20/06/90	7.3	177							11.84	13.94	13.96	0.0950	0.0440	0.0370	0.1200	0.0300	0.0220	0.350	0.130	0.120	0.0350	0.0150	0.0140	0.005900	0.002500	0.002400	
148	1372	Eshtehard	4	20/06/90	7.3	140							26.64	33.74	22.60	0.1600	0.0900	0.1700	0.7800	0.3000	0.7600	0.720	0.440	0.770	0.0610	0.0250	0.0600	0.010500	0.005700	0.012200	
149	1352	Tehran (BHRC)	1	20/06/90	7.3	209							8.85	8.81	8.55	0.0690	0.0340	0.0740	0.0740	0.1100	0.0520	0.271	0.146	0.209							
150	1357-2	Lahijan	4	26/06/90	4.2	45							9.00	9.01	9.01	0.0290	0.0220	0.0350	0.0083	0.0050	0.0120	0.111	0.237	0.135							
151	1393-2	Abbar	1	26/06/90	4.2	99							1.45	2.02	1.92	0.1400	0.0460	0.0850	0.0310	0.0470	0.0150	0.388	0.165	0.248							
152	1393-4	Abbar	1	28/06/90	4.8	24							4.22	3.30	4.45	0.0970	0.1300	0.0890	0.0440	0.0600	0.0390	0.601	0.598	0.470	0.0174	0.0117	0.0128	0.000609	0.000227	0.000314	
153	1367	Manjil	2	29/06/90	4.4	75							2.56	5.97	2.34	0.0410	0.0240	0.0540	0.0049	0.0039	0.0077	0.322	0.257	0.341	0.0040	0.0042	0.0064	0.000093	0.000088	0.000152	
154	1368-1	Rudbar	3	29/06/90	4.4	8							1.58	1.58	1.90	0.2700	0.2100	0.4500	0.1300	0.0740	0.2100	0.841	0.869	1.150	0.0173	0.0129	0.0308	0.000594	0.000329	0.001034	
155	1368-2	Rudbar	3	29/06/90	4.5	38							4.46	5.11	6.06	0.0520	0.0220	0.0320	0.0140	0.0027	0.0070	0.243	0.132	0.183							
156	1393-7	Abbar	1	29/06/90	4.5	36							4.28	10.																	

No	Record	Station	Site	Date	Mw	R(km)	Kh	Kv	Stress Drop (Bar)	Fc Corner freq. Hz	fmax (H) Hz	fmax (V) Hz	Dur (H1) sec	Dur (V) sec	Dur (H2) sec	Arms (H1) m/s	Arms (V) m/s	Arms (H2) m/s	Ea (H1) m2/s3	Ea (V) m2/s3	Ea (H2) m2/s3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	Vmax (H1) m/sec	Vmax (V) m/sec	Vmax (H2) m/sec	Dmax (H1) m	Dmax (V) m	Dmax (H2) m	
216	1502-8	Zanjiran	2	20/06/94	5.1	8	0.027	0.027	195.7	2.0	20.0	25.0	7.59	6.88	6.31	1600	1200	2000	2200	1100	2800	948	513	934	0.240	0.163	0.330	0.01969	0.01352	0.02315	
217	1492-16	Zarrat	1	20/06/94	5.9	29	0.042	0.034	629.0	1.0	10.0	11.0	7.67	11.09	6.17	7600	2500	8500	49000	7400	4900	3.058	1.038	2.569	1.108	0.357	0.955	0.27484	0.04789	0.12797	
218	1493-2	Fiروزabad	3	20/06/94	5.9	17	0.047	0.015	542.4	0.5	8.0	10.0	8.84	10.44	9.26	5000	2500	4100	24003	7400	1700	2.479	1.201	2.834	0.882	0.524	0.906	0.11052	0.10747	0.11059	
219	1495	Maharloo (PTT)	1	20/06/94	5.9	50					8.0	10.0	15.73	14.96	16.20	0.690	0.350	0.500	0.820	0.210	0.450	0.221	0.124	0.198	0.156	0.084	0.140	0.02986	0.01203	0.02859	
220	1498	Babanar	2	20/06/94	5.9	63							12.82	15.46	14.11	0.690	0.370	0.700	0.670	0.240	0.770	0.286	0.153	0.393	0.153	0.153	0.156	0.03515	0.04010	0.04309	
221	1502-9	Zanjiran	2	20/06/94	5.9	7	0.012	0.036	754.8	1.0	18.0	22.0	5.46	4.32	5.56	2.500	2.400	2.800	39.000	27.000	50.000	10.302	9.492	10.163	0.3271	0.1618	0.4100	0.034226	0.11762	0.26371	
222	1492-17	Zarrat	1	20/06/94	4.5	16	0.053	0.015	184.5	2.2	18.0	18.0	9.58	10.60	9.00	0.380	0.190	0.400	0.150	0.042	0.160	0.214	0.078	0.227	0.072	0.020	0.066	0.00336	0.00099	0.00294	
223	1492-18	Zarrat	1	20/06/94	4.0	16	0.055	0.056	197.3	4.0	11.0	15.0	5.44	6.43	5.71	0.230	0.120	0.250	0.033	0.010	0.040	0.090	0.038	0.129	0.022	0.008	0.037	0.00093	0.00045	0.00130	
224	1493-3	Fiروزabad	3	20/06/94	4.3	18	0.050	0.041	135.7	2.5	6.0	8.0	10.14	9.68	10.40	0.340	0.230	0.310	0.130	0.059	0.110	0.128	0.078	0.135	0.043	0.025	0.038	0.00254	0.00142	0.00232	
225	1492-19	Zarrat	1	21/06/94	4.5	15	0.046	0.050	191.6	2.5	10.0	12.0	7.32	9.10	8.09	0.450	0.180	0.400	0.160	0.034	0.150	0.157	0.105	0.193	0.051	0.026	0.047	0.00276	0.00207	0.00283	
226	1492-20	Zarrat	1	21/06/94	4.7	16	0.040	0.059	525.9	3.5	10.0	15.0	7.57	10.11	8.14	0.690	0.220	0.590	0.400	0.057	0.320	0.269	0.085	0.181	0.090	0.022	0.063	0.00543	0.00285	0.00413	
227	1493-4	Fiروزabad	3	21/06/94	4.7	18	0.042	0.034	191.6	2.5	7.0	8.0	9.95	10.19	9.31	0.380	0.220	0.320	0.140	0.052	0.110	0.129	0.090	0.109	0.047	0.027	0.036	0.00305	0.00235	0.00209	
228	1492-21	Zarrat	1	21/06/94	4.1	18	0.083	0.036	396.8	4.5	18.0	18.0	5.16	5.95	5.53	0.320	0.210	0.370	0.060	0.029	0.084	0.159	0.095	0.157	0.033	0.014	0.028	0.00108	0.00051	0.00072	
229	1492-22	Zarrat	1	21/06/94	4.3	15	0.079	0.062	197.3	4.0	10.0	12.0	7.32	7.69	6.41	0.230	0.120	0.270	0.042	0.013	0.053	0.111	0.046	0.106	0.031	0.011	0.031	0.00198	0.00175	0.00192	
230	1518-1	Fiروزabad	3	22/06/94	3.1	4	0.035	0.030	17.2	5.0	30.0	30.0	6.3	1.30	3.55	1100	0160	0110	0079	0004	0005	0359	073	084	0042	0008	0010	0.00239	0.00046	0.00061	
231	1501-1	Zanjiran	2	23/06/94	3.7	12	0.023	0.021	501.4	8.0	20.0	22.0	1.05	1.87	1.80	2600	1000	3300	0800	0220	0990	842	374	1.092	0.113	0.037	0.015	0.025	0.00211	0.00062	0.00061
232	1501-2	Zanjiran	2	23/06/94	3.1	8	0.031	0.061	70.6	8.0	22.0	25.0	2.06	1.77	1.11	0.340	0.240	0.530	0.026	0.012	0.035	0.153	0.106	0.234	0.018	0.011	0.033	0.00041	0.00047	0.00062	
233	1501-3	Zanjiran	2	23/06/94	3.8	12	0.003	0.019	41.7	3.0	22.0	25.0	4.65	5.98	5.10	0.250	0.140	0.230	0.033	0.013	0.030	0.197	0.065	0.168	0.032	0.007	0.030	0.00110	0.00052	0.00107	
234	1492-23	Zarrat	1	24/06/94	4.0	20	0.033	0.052	544.3	5.0	10.0	12.0	6.86	7.73	6.95	0.400	0.190	0.480	0.120	0.031	0.150	0.155	0.082	0.189	0.043	0.016	0.043	0.00195	0.00119	0.00196	
235	1501-4	Zanjiran	2	24/06/94	4.0	15	0.023	0.021	132.2	3.5	20.0	22.0	7.03	5.82	6.16	0.290	0.250	0.350	0.066	0.040	0.084	0.096	0.117	0.184	0.022	0.021	0.036	0.00120	0.00141	0.00130	
236	1501-5	Zanjiran	2	24/06/94	3.7	8	0.031	0.030	182.1	5.5	20.0	22.0	1.29	2.76	.91	0.720	0.240	0.400	0.074	0.018	0.200	0.248	0.097	0.476	0.034	0.009	0.075	0.00084	0.00047	0.00157	
237	1501-6	Zanjiran	2	24/06/94	3.6	5	0.021	0.023	49.6	4.0	25.0	30.0	2.47	2.15	2.38	0.450	0.320	0.430	0.054	0.025	0.049	0.250	0.122	0.198	0.039	0.012	0.022	0.00128	0.00085	0.00079	
238	1501-7	Zanjiran	2	24/06/94	4.5	8	0.029	0.017	270.6	2.5	22.0	25.0	2.77	2.95	2.06	0.260	0.170	0.310	0.100	0.089	0.210	0.1352	0.596	1.367	0.286	0.069	0.188	0.01587	0.00242	0.00633	
239	1501-8	Zanjiran	2	25/06/94	3.6	12	0.049	0.021	128.9	5.5	20.0	25.0	1.28	2.72	1.34	0.470	0.180	0.430	0.032	0.010	0.320	0.486	0.238	0.438	0.067	0.026	0.079	0.00157	0.00082	0.00300	
240	1501-9	Zanjiran	2	25/06/94	4.2	8	0.031	0.021	263.6	3.5	25.0	30.0	1.81	2.89	1.88	1600	0610	1200	0490	0120	0320	486	238	0.438	0.067	0.026	0.079	0.00157	0.00082	0.00300	
241	1523-1	Jovakan	1	06/07/94	3.4	12	0.045	0.039	48.6	5.0	20.0	20.0	3.14	2.60	3.97	0.250	0.200	0.180	0.022	0.011	0.015	0.199	0.144	0.114	0.024	0.013	0.014	0.00072	0.00063	0.00034	
242	1523-2	Jovakan	1	07/07/94	4.0	12	0.038	0.025	48.2	2.5	18.0	18.0	5.61	6.89	5.28	0.320	0.190	0.340	0.062	0.027	0.066	0.148	0.073	0.139	0.046	0.012	0.047	0.00247	0.00083	0.00240	
243	1523-3	Jovakan	1	07/07/94	3.8	16	0.034	0.038	98.9	4.0	20.0	20.0	4.88	5.51	5.16	0.440	0.270	0.390	0.110	0.045	0.089	0.261	0.166	0.293	0.036	0.024	0.044	0.00137	0.00082	0.00142	
244	1523-4	Jovakan	1	09/07/94	4.0	18	0.060	0.053	132.2	3.5	20.0	20.0	2.20	4.61	2.71	0.670	0.280	0.520	0.110	0.041	0.081	0.339	0.153	0.233	0.059	0.016	0.041	0.00137	0.00082	0.00142	
245	1519-1	Zarrat	1	10/07/94	3.9	20	0.094	0.053	272.8	5.0	18.0	18.0	5.51	6.67	5.29	0.220	0.110	0.200	0.029	0.009	0.023	0.133	0.050	0.099	0.026	0.009	0.020	0.00096	0.00063	0.00086	
246	1523-5	Jovakan	1	10/07/94	3.5	16	0.042	0.040	68.5	5.0	18.0	20.0	4.51	3.67	4.59	0.200	0.170	0.170	0.021	0.012	0.015	0.154	0.095	0.112	0.021	0.008	0.013	0.00052	0.00040	0.00074	
247	1518-2	Fiروزabad	3	13/07/94	4.2	16	0.035	0.043	96.1	2.5	6.0	10.0	9.54	8.01	8.77	0.210	0.160	0.220	0.048	0.024	0.046	0.126	0.076	0.080	0.027	0.016	0.027	0.00123	0.00100	0.00143	
248	1523-6	Jovakan	1	13/07/94	4.2	16	0.054	0.037	49.2	2.0	18.0	18.0	6.28	7.73	6.65	0.500	0.270	0.480	0.180	0.069	0.170	0.288	0.158	0.263	0.066	0.029	0.057	0.00231	0.00169	0.00260	
249	1523-7	Jovakan	1	16/07/94	4.3	16	0.040	0.024	555.8	4.0	18.0	18.0	6.23	7.53	6.26	0.200	0.120	0.220	0.029	0.011	0.035	0.129	0.067	0.142	0.027	0.010	0.026	0.00116	0.00107	0.00067	
250	1523-8	Jovakan	1	18/07/94	3.8	14	0.054	0.044	24.1	2.5	21.0	21.0	5.92	6.93	4.63	0.440	0.260	0.500	0.130	0.051	0.130	0.183	0.112	0.184	0.035	0.019	0.042	0.00142	0.00129	0.00194	
251	1523-9	Jovakan	1	20/07/94	3.7	15	0.027	0.022	70.1	4.0	10.0	10.0	2.76	7.78	3.30	0.250	0.080	0.190	0.020	0.005	0.013	0.190	0.043	0.113	0.028	0.007	0.019	0.00089	0.00041	0.00062	
252	1513	Bandar-Torkman	4	23/07/94	5.1	60	0.079		566.2	1.5	5.0	5.0	15.53	18.89	14.53	0.500	0.220	0.610	0.440	0.110	0.590	0.181	0.083	0.279	0.122	0.059	0.164	0.03218	0.01598	0.03368	
253	1523-11	Jovakan	1	24/07/94	3.4	12	0.025	0.015	83.9	6.0	21.0	21.0	4.26	3.65	3.02	0.240	0.230	0.350	0.027	0.021	0.042	0.129	0.180	0.224	0.021	0.016	0.032	0.00062	0.00062	0.00110	
254	1523-12	Jovakan	1	28/07/94	3.4	12	0.038	0.024	48.6	5.0	21.0	21.0	1.30	3.65	1.21	0.580	0.180	0.580	0.048	0.013	0.045	0.307	0.114	0.260	0.041	0.014	0.031	0.00120	0.00049	0.00086	
255	1523-13	Jovakan	1	29/07/94	3.7	12	0.031	0.032	136.8	5.0	28.0	28.0	2.50	9.44	4.51	0.240	0.060	0.110	0.016	0.004											

No	Record	Station	Site	Date	Mw	R(km)	Kh	Kv	Stress Drop (Bar)	Fc Corner freq. Hz	fmax (H) Hz	fmax (V) Hz	Dur (H1) sec	Dur (V) sec	Dur (H2) sec	Arms (H1) m/s	Arms (H2) m/s	Arms (H3) m/s	Ea (H1) m2/s3	Ea (V) m2/s3	Ea (H2) m2/s3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	Vmax (H1) m/sec	Vmax (V) m/sec	Vmax (H2) m/sec	Dmax (H1) m	Dmax (V) m	Dmax (H2) m
324	1528-28	Fin	3	24/01/95	3.9	16	0.034	0.055	139.7	4.0	20.0	28.0	7.23	3.87	5.36	0.280	0.280	0.400	0.063	0.034	0.094	203	126	214	0.035	0.022	0.036	0.00146	0.00065	0.00115
325	1528-29	Fin	3	24/01/95	4.2	12	0.023	0.027	263.6	3.5	20.0	25.0	6.90	5.62	8.76	0.610	0.440	0.430	0.280	0.120	0.180	402	209	276	0.083	0.043	0.037	0.00378	0.00136	0.00143
326	1528-10	Fin	3	24/01/95	4.6	16	0.026	0.054	377.4	2.5	20.0	22.0	4.29	4.24	3.57	0.290	0.300	0.370	0.410	0.770	0.400	1.652	0.617	1.165	0.412	0.154	0.037	0.02362	0.00628	0.00136
327	1528-11	Fin	3	24/01/95	3.9	12	0.030	0.044	58.9	3.0	19.0	22.0	2.95	3.21	3.88	0.460	0.340	0.350	0.069	0.041	0.053	268	121	183	0.039	0.016	0.026	0.00085	0.00066	0.00102
328	1528-12	Fin	3	24/01/95	4.1	6	0.040	0.035	186.7	3.5	20.0	25.0	5.50	5.55	5.84	1.500	0.910	1.300	1.400	0.520	0.200	0.370	0.512	0.841	0.182	0.080	0.144	0.01056	0.00254	0.00659
329	1528-13	Fin	3	24/01/95	3.9	10	0.037	0.058	58.9	3.0	22.0	28.0	1.84	3.26	2.53	0.670	0.330	0.550	0.093	0.041	0.086	370	132	380	0.036	0.017	0.030	0.00071	0.00071	0.00073
330	1528-14	Fin	3	24/01/95	3.8	8	0.022	0.039	66.3	3.5	20.0	22.0	10.89	11.95	11.05	0.280	0.210	0.320	0.093	0.059	0.130	171	137	226	0.039	0.017	0.039	0.00320	0.00095	0.00129
331	1528-15	Fin	3	24/01/95	3.5	6	0.040	0.041	35.1	4.0	22.0	28.0	1.66	1.88	1.95	0.620	0.480	1.200	0.072	0.048	0.150	395	275	605	0.031	0.027	0.049	0.00072	0.00062	0.00072
332	1528-16	Fin	3	24/01/95	4.1	14	0.047		68.0	2.5	19.0	22.0	11.80	8.55	10.75	0.280	0.300	0.430	0.099	0.085	0.220	173	141	263	0.024	0.020	0.029	0.00147	0.00085	0.00101
333	1528-17	Fin	3	24/01/95	3.9	14	0.026	0.039	65.0	3.5	22.0	28.0	4.56	3.24	5.46	0.640	0.530	0.510	0.210	0.099	0.160	544	214	385	0.060	0.027	0.030	0.00277	0.00097	0.00158
334	1528-18	Fin	3	24/01/95	3.8	12	0.032	0.035	66.2	3.5	20.0	22.0	1.76	2.41	2.88	0.550	0.360	0.420	0.059	0.035	0.056	370	134	289	0.035	0.016	0.021	0.00054	0.00054	0.00058
335	1528-19	Fin	3	24/01/95	3.9	8	0.037	0.054	58.9	3.0	22.0	28.0	7.53	5.77	7.07	0.270	0.230	0.310	0.061	0.032	0.077	123	119	162	0.022	0.015	0.029	0.00155	0.00051	0.00114
336	1528-20	Fin	3	24/01/95	4.1	20	0.031	0.024	186.7	3.5	20.0	25.0	3.76	3.82	4.43	0.440	0.320	0.460	0.082	0.043	0.110	219	112	222	0.046	0.026	0.034	0.00262	0.00093	0.00194
337	1528-21	Fin	3	24/01/95	4.1	12	0.032	0.039	117.5	3.0	19.0	20.0	9.06	6.07	6.80	0.300	0.250	0.460	0.090	0.041	0.160	130	105	245	0.033	0.014	0.041	0.00262	0.00093	0.00194
338	1528-4	Fin	3	24/01/95	4.0	8	0.045	0.003	132.2	3.5	18.0	22.0	5.18	4.40	6.23	0.810	0.570	0.700	0.080	0.160	0.340	420	256	385	0.076	0.036	0.057	0.00298	0.00159	0.00330
339	1528-5	Fin	3	24/01/95	4.1	6	0.044	0.062	117.5	3.0	18.0	22.0	5.04	4.03	5.80	0.620	0.430	0.810	0.220	0.075	0.340	357	210	346	0.093	0.043	0.106	0.00315	0.00140	0.00356
340	1528-6	Fin	3	24/01/95	4.0	8	0.055	0.063	132.2	3.5	21.0	26.0	5.13	3.74	4.59	0.620	0.430	0.810	0.220	0.075	0.340	357	210	346	0.093	0.043	0.106	0.00315	0.00140	0.00356
341	1528-7	Fin	3	24/01/95	3.7	8	0.031	0.018	46.9	3.5	20.0	22.0	3.49	2.73	3.77	0.380	0.330	0.380	0.049	0.032	0.061	239	190	251	0.053	0.037	0.042	0.00161	0.00106	0.00157
342	1528-8	Fin	3	24/01/95	4.1	16	0.032	0.042	186.7	3.5	18.0	22.0	6.81	3.89	6.09	0.430	0.410	0.450	0.140	0.071	0.140	406	229	251	0.053	0.037	0.042	0.00161	0.00106	0.00157
343	1528-9	Fin	3	24/01/95	4.0	14	0.050	0.002	132.2	3.5	20.0	22.0	3.37	3.13	2.78	0.660	0.470	0.870	0.160	0.078	0.230	435	259	469	0.045	0.033	0.047	0.00216	0.00200	0.00401
344	1528-30	Fin	3	25/01/95	3.9	12	0.029	0.033	93.6	3.5	20.0	20.0	7.24	3.90	8.68	0.450	0.430	0.350	0.160	0.081	0.120	365	223	277	0.054	0.031	0.030	0.00268	0.00084	0.00099
345	1528-31	Fin	3	25/01/95	4.0	16	0.029		132.2	3.5	15.0	18.0	6.83	4.80	5.67	0.280	0.250	0.400	0.060	0.033	0.100	171	115	184	0.025	0.019	0.035	0.00082	0.00062	0.00130
346	1631-1	Musian	3	27/01/95	4.1	16	0.041	0.050	117.5	3.0	16.0	18.0	1.84	3.69	1.39	0.560	0.270	0.640	0.064	0.030	0.063	184	112	112	0.037	0.016	0.046	0.00141	0.00224	0.00248
347	1592	Golbaf	3	17/02/95	4.4	12	0.056	0.035	41.4	1.5	8.0	12.0	5.66	4.84	5.05	0.360	0.300	0.320	0.081	0.047	0.058	148	112	100	0.081	0.026	0.057	0.001297	0.00268	0.00569
348	1555	Fiروزabad	3	19/02/95	4.7	19	0.058	0.042	117.6	3.0	9.0	15.0	6.89	6.99	6.13	0.250	0.190	0.330	0.047	0.027	0.075	163	094	232	0.037	0.016	0.046	0.00141	0.00224	0.00248
349	1547-1	Sefidrud Dam	1	07/03/95	2.7	15							2.13	4.38	3.05	1.900	0.270	0.330	0.080	0.035	0.037	552	128	147	0.182	0.024	0.052	0.00692	0.00155	0.00309
350	1535-1	Rudbar	3	07/03/95	3.9	10	0.024	0.030	139.7	4.0	18.0	20.0	2.00	2.84	2.13	0.510	0.480	0.550	0.059	0.071	0.255	164	274	0.057	0.023	0.074	0.00212	0.00147	0.00414	
351	1563	Dorahun	3	08/03/95	4.3	13	0.029	0.035	37.7	2.0	18.0	20.0	4.80	6.10	4.81	0.430	0.160	0.420	0.096	0.017	0.096	161	062	157	0.047	0.016	0.046	0.00216	0.00200	0.00401
352	1564-1	Khanzanun	1	09/03/95	4.1	16	0.041	0.016	34.8	2.0	12.0	18.0	4.15	5.59	4.74	0.250	0.170	0.190	0.029	0.017	0.020	173	125	117	0.033	0.019	0.021	0.00169	0.00129	0.00079
353	1554	Baba-Monir	4	22/03/95	4.8	23	0.053	0.032			10.0	12.0	12.01	11.19	11.84	0.420	0.310	0.470	0.230	0.120	0.290	184	140	203	0.060	0.031	0.086	0.00344	0.00220	0.00512
354	1575-1	Babakalan (Gachsaran)	2	22/03/95	4.8	20	0.057	0.114	150.9	5.0	18.0	20.0	3.40	5.39	5.99	0.550	0.310	0.540	0.110	0.059	0.190	242	145	207	0.035	0.016	0.040	0.00114	0.00074	0.00190
355	1650-1	Fiروزabad	3	25/03/95	4.7	12	0.058	0.023	166.4	1.5	6.0	11.0	6.43	7.20	8.03	0.860	0.470	0.650	0.530	0.180	0.370	302	191	294	0.166	0.070	0.104	0.01848	0.00665	0.01492
356	1545-1	Kavar	2	02/04/95	4.5	40	0.030	0.026	142.7	1.8	11.0	15.0	9.77	9.91	10.71	0.420	0.250	0.340	0.190	0.070	0.140	209	123	147	0.059	0.018	0.032	0.00326	0.00149	0.00321
357	1562-1	Zarrat	1	02/04/95	4.8	30	0.062	0.030	393.5	3.5	10.0	15.0	9.03	10.36	9.86	0.550	0.220	0.400	0.300	0.057	0.170	292	116	145	0.070	0.019	0.045	0.00245	0.00173	0.00189
358	1545-2	Kavar	2	04/04/95	4.0	12	0.014	0.061	48.2	2.5	9.0	11.0	2.47	3.91	2.79	0.360	0.150	0.310	0.035	0.010	0.030	144	071	159	0.034	0.011	0.028	0.00129	0.00082	0.00094
359	1590-1	Sisakht	1	06/04/95	3.5	16	0.020	0.017	452.9	9.0	30.0	33.0	2.48	2.88	2.94	0.780	0.790	0.690	0.170	0.200	0.160	261	317	273	0.037	0.034	0.062	0.00191	0.00139	0.00247
360	1562-2	Zarrat	1	16/04/95	4.2	16	0.033	0.059			12.0	18.0	5.81	5.55	7.01	0.570	0.400	0.430	0.210	0.099	0.140	275	185	160	0.062	0.034	0.062	0.00191	0.00139	0.00247
361	1655	Saman	2	18/04/95	3.7	14	0.017	0.019	44.0	5.0	25.0	28.0	4.31	5.18	4.88	0.350	0.210	0.350	0.059	0.025	0.067	182	088	136	0.021	0.010	0.026	0.00050	0.00030	0.00051
362	1556	Bandar-Deylam	4	22/04/95	5.1	95	0.088	0.016	68.9	1.0	3.0		11.09	12.27	10.17	0.190	0.042	0.230	0.043	0.002	0.061	056	013	105	0.047	0.011	0.102	0.00965	0.00110	0.01501
363	1581	Lendeh	1	22/04/95	5.1	51	0.068	0.075	25.4	0.8	8.0	10.0	11.90	12.43	12.84	0.510	0.290	0.420	0.340	0.120	0.250	181	126	204	0.118	0.085	0.122	0.01377	0.01240	0.01757
364	1535-2	Rudbar	3	26/04/95	4.8	8	0.058	0.039	276.4	2.0	18.0	20.0																		

No	Record	Station	Site	Date	Mw	R(km)	Kh	Kv	Stress Drop (Bar)	Fc Corner freq. Hz	fmax (H) Hz	fmax (V) Hz	Dur (H1) sec	Dur (V) sec	Dur (H2) sec	Arms (H1) m/s	Arms (V) m/s	Arms (H2) m/s	Ea (H1) m2/s3	Ea (V) m2/s3	Ea (H2) m2/s3	PGA (H1) m/sec2	PGA (V) m/sec2	PGA (H2) m/sec2	Vmax (H1) m/sec	Vmax (V) m/sec	Vmax (H2) m/sec	Dmax (H1) m	Dmax (V) m	Dmax (H2) m
425	1571-2	Shabankareh	4	23/01/96	3.5	16	0.026	0.050	120.8	6.0	15.0	18.0	2.25	4.45	3.95	.0410	.0280	.0230	.0043	.0038	.0023	.236	.123	.087	.0043	.0017	.0014	.000140	.000052	.000065
426	1571-3	Shabankareh	4	23/01/96	3.7	16	0.071	0.064	125.8	5.0	12.0	16.0	8.97	4.18	3.90	.0130	.0420	.0420	.0017	.0082	.0078	.086	.175	.314	.0016	.0021	.0046	.000060	.000060	.000198
427	1571-8	Shabankareh (Borazjan)	4	24/01/96	4.5	18	0.035	0.030	339.7	3.0	16.0	21.0	2.76	5.71	3.83	.2100	.0830	.1400	.1300	.0440	.0790	1.181	.365	.641	.0274	.0052	.0156	.001395	.000141	.000637
428	1571-11	Shabankareh (Borazjan)	4	24/01/96	4.4	18	0.035	0.024	198.9	4.5	18.0	22.0	6.84	7.84	8.04	.0200	.0150	.0170	.0031	.0019	.0026	.128	.065	.121	.0031	.0012	.0031	.000091	.000022	.000130
429	1571-16	Shabankareh (Borazjan)	4	24/01/96	4.7	16	0.026	0.054	272.9	5.0	18.0	20.0	7.48	10.72	8.65	.0250	.0180	.0240	.0051	.0040	.0057	.184	.109	.213	.0047	.0018	.0051	.000115	.000047	.000250
430	1583-3	Saadabad (Borazjan)	1	24/01/96	4.4	21	0.029	0.018	377.4	3.0	18.0	20.0	13.22	17.01	14.99	.0750	.0280	.0550	.0820	.0150	.0500	.726	.215	.442	.0194	.0050	.0156	.001174	.000223	.000623
431	1583-4	Saadabad	1	24/01/96	4.7	21	0.017	0.018			12.0	18.0	5.07	8.75	5.28	.0470	.0180	.0390	.0130	.0032	.0087	.331	.092	.176	.0120	.0020	.0046	.000542	.000112	.000198
432	1571-10	Shabankareh	4	24/01/96	4.6	24	0.035	0.017	679.4	3.0	11.0	18.0	19.32	16.75	16.48	.0720	.0770	.1000	.1100	.1100	.1900	.534	.418	.837	.0154	.0070	.0303	.000676	.000294	.001397
433	1571-12	Shabankareh	4	24/01/96	3.7	20	0.052	0.027	236.4	6.0	11.0	15.0	5.44	6.69	5.50	.0160	.0160	.0170	.0016	.0019	.0019	.103	.104	.117	.0026	.0015	.0030	.000067	.000079	.000268
434	1571-13	Shabankareh	4	24/01/96	3.7	18	0.037	0.018	182.1	5.5	10.0	18.0	7.39	7.95	3.99	.0150	.0140	.0290	.0020	.0019	.0037	.123	.092	.193	.0025	.0013	.0050	.000067	.000079	.000268
435	1571-14	Shabankareh	4	24/01/96	3.7	16	0.048	0.036	182.1	5.5	10.0	12.0	7.93	7.55	4.62	.0160	.0140	.0270	.0021	.0016	.0038	.117	.077	.214	.0031	.0015	.0052	.000118	.000068	.000206
436	1571-15	Shabankareh	4	24/01/96	3.6	15	0.048	0.051	128.9	5.5	10.0	12.0	5.39	6.06	4.96	.0190	.0190	.0230	.0021	.0021	.0020	.105	.105	.146	.0013	.0012	.0025	.000051	.000050	.000109
437	1571-17	Shabankareh	4	24/01/96	3.5	17	0.030	0.019	160.7	6.5	18.0	22.0	7.05	5.38	4.14	.0110	.0190	.0210	.0010	.0021	.0020	.105	.105	.146	.0013	.0012	.0025	.000051	.000050	.000109
438	1571-18	Shabankareh	4	24/01/96	3.5	18	0.036	0.081	167.4	6.0	18.0	20.0	12.73	9.53	5.59	.0047	.0076	.0150	.0003	.0006	.0013	.032	.047	.116	.0008	.0006	.0025	.000052	.000053	.000091
439	1571-19	Shabankareh	4	24/01/96	3.8	16	0.041	0.023	333.9	6.0	12.0	18.0	8.15	8.21	8.20	.0170	.0160	.0170	.0027	.0023	.0025	.102	.061	.133	.0027	.0012	.0032	.000106	.000087	.000280
440	1571-20	Shabankareh	4	24/01/96	3.8	16	0.006	0.015	140.9	3.5	18.0	22.0	10.89	7.41	5.34	.0200	.0330	.0680	.0050	.0089	.00270	.080	.152	.499	.0019	.0022	.0168	.000080	.000138	.000662
441	1571-21	Shabankareh	4	24/01/96	3.7	16	0.036	0.051	236.4	6.0	12.0	15.0	11.76	10.16	10.05	.0130	.0130	.0170	.0023	.0020	.0032	.116	.078	.172	.0026	.0011	.0047	.000106	.000087	.000280
442	1571-22	Shabankareh	4	24/01/96	4.0	16	0.057	0.047	140.9	3.5	18.0	22.0	10.89	7.41	5.34	.0200	.0330	.0680	.0050	.0089	.00270	.080	.152	.499	.0019	.0022	.0168	.000080	.000138	.000662
443	1571-23	Shabankareh	4	24/01/96	3.6	16	0.012	0.049	167.4	6.0	9.0	11.0	7.34	8.51	7.81	.0140	.0089	.0130	.0017	.0008	.0015	.109	.035	.083	.0029	.0006	.0025	.000193	.000063	.000149
444	1571-24	Shabankareh	4	24/01/96	4.0	20	0.059	0.056	197.3	4.0	9.0	11.0	7.34	8.51	7.81	.0140	.0089	.0130	.0017	.0008	.0015	.109	.035	.083	.0029	.0006	.0025	.000193	.000063	.000149
445	1571-25	Shabankareh	4	24/01/96	3.9	20	0.042	0.032	110.1	3.5	15.0	19.0	5.85	6.45	5.28	.0280	.0280	.0370	.0051	.0056	.0082	.199	.145	.260	.0042	.0020	.0018	.000077	.000031	.000274
446	1571-4	Shabankareh	4	24/01/96	3.9	17	0.040	0.042	171.1	5.0	15.0	18.0	8.52	5.36	4.32	.0150	.0320	.0430	.0021	.0059	.0089	.082	.164	.342	.0020	.0018	.0064	.000077	.000031	.000274
447	1571-5	Shabankareh	4	24/01/96	3.8	16	0.017	0.066	120.8	4.0	12.0	18.0	8.44	6.00	3.71	.0170	.0280	.0530	.0028	.0053	.0120	.121	.134	.380	.0029	.0018	.0083	.000140	.000036	.000350
448	1571-6	Shabankareh	4	24/01/96	3.7	16	0.040	0.048	80.5	4.0	15.0	18.0	8.46	5.12	3.98	.0150	.0290	.0410	.0021	.0048	.0075	.100	.166	.246	.0026	.0022	.0063	.000104	.000045	.000263
449	1571-7	Shabankareh	4	24/01/96	4.2	17	0.039	0.035	768.4	4.0	15.0	20.0	8.99	5.66	5.58	.0390	.0730	.0970	.0150	.0340	.0580	.199	.267	.632	.0044	.0040	.0129	.000191	.000094	.000681
450	1571-9	Shabankareh	4	24/01/96	3.7	17	0.038	0.026	64.2	4.0	11.0	15.0	7.15	5.48	2.94	.0100	.0150	.0280	.0008	.0013	.0026	.083	.064	.179	.0017	.0010	.0037	.000065	.000023	.000143
451	1583-5	Saadabad	1	24/01/96	4.2	22	0.017	0.010	96.1	2.5	20.0	22.0	3.75	7.16	3.99	.0350	.0120	.0280	.0050	.0011	.0035	.227	.046	.215	.0073	.0018	.0056	.000207	.000111	.000146
452	1583-6	Saadabad	1	24/01/96	4.1	25	0.043	0.032	186.7	3.5	18.0	18.0	5.11	5.60	3.93	.0220	.0150	.0320	.0027	.0015	.0045	.152	.092	.172	.0034	.0021	.0046	.000190	.000076	.000261
453	1571-30	Shabankareh (Borazjan)	4	25/01/96	4.5	20	0.062	0.024	201.3	4.0	12.0	20.0	6.46	6.46	5.55	.0380	.0410	.0460	.0100	.0120	.0130	.216	.144	.235	.0046	.0026	.0057	.000218	.000067	.000229
454	1583-7	Saadabad (Borazjan)	1	25/01/96	4.5	21	0.022	0.010	69.5	2.0	12.0	19.0	3.76	6.65	4.90	.0360	.0140	.0240	.0055	.0015	.0031	.220	.061	.172	.0081	.0015	.0053	.000422	.000062	.000188
455	1571-26	Shabankareh	4	25/01/96	4.0	20	0.035	0.021	201.3	4.0	20.0	25.0	7.16	4.73	2.45	.0340	.0660	.1500	.0093	.0230	.0650	.236	.270	.811	.0045	.0036	.0161	.000093	.000091	.000755
456	1571-27	Shabankareh	4	25/01/96	3.7	20	0.049	0.031	236.4	6.0	11.0	15.0	6.36	5.57	6.13	.0160	.0210	.0160	.0018	.0028	.0017	.089	.096	.121	.0025	.0013	.0021	.000085	.000067	.000089
457	1571-28	Shabankareh	4	25/01/96	3.9	20	0.059	0.056	362.2	5.5	12.0	15.0	6.15	4.51	5.34	.0250	.0390	.0350	.0044	.0076	.0072	.213	.187	.277	.0034	.0026	.0053	.000150	.000065	.000239
458	1571-29	Shabankareh	4	25/01/96	4.0	20	0.062	0.024	280.9	5.5	11.0	19.0	6.47	6.46	5.55	.0380	.0410	.0460	.0100	.0120	.0130	.214	.144	.237	.0048	.0027	.0058	.000301	.000093	.000372
459	1571-31	Shabankareh	4	25/01/96	3.6	20	0.029	0.011	50.3	4.0	13.0	20.0	7.04	6.44	4.78	.0092	.0160	.0210	.0007	.0018	.0023	.043	.093	.135	.0011	.0010	.0030	.000053	.000079	.000106
460	1571-32	Shabankareh	4	26/01/96	3.9	21	0.049	0.019	166.1	4.0	13.0	20.0	6.23	4.86	4.32	.0360	.0570	.0650	.0090	.0170	.0200	.245	.242	.437	.0012	.0011	.0027	.000260	.000321	.000149
461	1571-34	Shabankareh	4	26/01/96	4.6	20	0.025	0.019	128.9	5.5	11.0	18.0	7.49	6.51	4.82	.0100	.0130	.0170	.0008	.0012	.0015	.055	.069	.123	.0012	.0011	.0032	.0003	.000457	.000653
462	1571-35	Shabankareh	4	26/01/96	4.4	22	0.027	0.072	135.8	5.5	10.0	11.0	7.24	6.80	6.73	.0450	.0380	.0440	.0170	.0110	.0150	.281	.167	.354	.0086	.0032	.0093	.001473	.000172	.001124
463	1589-1	Saadabad	1	26/01/96	4.6	22	0.030	0.031	331.1	3.0	15.0	15.0	9.35	12.58	9.97	.0260	.0110	.0260	.0030	.0010	.0035	.153	.050	.152	.0041	.0010	.0048	.000308	.000056	.000217
464	1589-2	Saadabad	1	26/01/96	4.4	22	0.034	0.023	69.5	2.0			4.09	7.88	4.59	.0260	.0110	.0260	.0030	.0010	.0035	.153	.050	.152	.0041	.0010	.0048	.000308	.000056	.000217
465	1599-1	Fiروزabad	3	26/01/96	4.4	26	0.037	0.043	166.4	3.0	8.0	10.0	8.76	9.12	9.84	.0490	.0280	.0340	.0240	.0080	.0120	.234	.140	.111	.0088	.0031	.0034	.000465	.000206	.000300
466	1571-33	Shabankareh	4	26/01/96																										

Thèse de Doctorat de l'Université Joseph Fourier
Grenoble I

Titre de l'ouvrage:

CONTRIBUTION À L'ÉTUDE DES MOUVEMENTS FORTS EN IRAN; DU CATALOGUE AUX LOIS D'ATTÉNUATION

Auteur: Mehdi ZARÉ

Etablissement: Laboratoire de Géophysique Interne et Tectonophysique

Résumé:

Les études de risque sismique en Iran sont dans leur phase initiale. Ainsi, il n'existait jusqu'à présent aucun catalogue d'enregistrements accélérométriques en Iran, et aucune étude sur l'ensemble des données iraniennes n'avait été réalisée. Ce mémoire présente donc la première étude d'ensemble sur les mouvements forts en Iran. Un premier objectif a été d'établir un catalogue des mouvements forts d'Iran en faisant correspondre à chaque enregistrement de qualité suffisante, un événement sismique de localisation et magnitude connues, pour 279 enregistrements accélérométriques, analogues et digitaux. Cette correspondance a pu se faire sur la base des catalogues sismologiques internationaux (ISC, NEIC,... etc.) ou nationaux. Pour 189 autres enregistrements numériques, pour lesquelles aucune information télé-sismique ou locale n'était disponible, les distances hypocentrales et les moments sismiques ont été estimés sur la base des enregistrements eux-mêmes. Une attention particulière a été accordée aux effets de sites, en choisissant notamment 50 stations accélérométriques du réseau national où les enregistrements ont été nombreux. Une nouvelle classification pour les effets de sites est proposée - basée sur les rapports H/V - qui s'avère relativement simple dans son principe, et plus fiable que les classifications déjà utilisées. Finalement, les lois d'atténuation pour différents paramètres de mouvement fort (dont Arms, Intensité Arias, PGA, PGV, et PGD, énergie, durée et valeurs spectrales) sont obtenues et discutées sur la base d'un total de 468 enregistrements accélérométriques en 3 composantes.

Mots Clés: Sismologie de l'ingénieur, Iran, mouvements forts, effets de site, loi d'atténuation, moment sismique, chute de contrainte, source, accélérograms, catalogue, durée, énergie, Zagros, Alborz, Iran-central